IN-18

61948

P-79

NASA Technical Memorandum 104169

SPACE STATION FREEDOM CONTINGENCY REBOOST AND RESUPPLY STRATEGIES

(NASA-TM-104169) SPACE STATION FREEDOM CONTINGENCY REBOOST AND RESUPPLY STRATEGIES (NASA) 79 p CSCL 22B

N92-15116

Unclas

G3/18 0061948

Patrick A. Troutman
Jonathan N. Cruz
Michael L. Heck
Daniel D. Mazanek
Renjith R. Kumar

OCTOBER 1991

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

Introduction

This study was performed to determine the requirements necessary to ensure a viable space station in the event of a delay in the date of the first element launch, and/or in the event that the nominal assembly sequence is interrupted, perhaps due to a delay in the space shuttle launch schedule. Orbit lifetimes, reboost fuel requirements and controllability requirements were calculated for each stage of the space station assuming anywhere from a 6 to 24 month delay/interruption in the baseline space station assembly sequence. These results were assessed in order to formulate reboost/altitude strategies to assure station viability in the presence of assembly sequence delays and interruptions.

Objective

The objective of the study was to define the requirements necessary to insure a viable space station in the event of a delay in the date of first element launch, and/or in the event that the nominal rendezvous sequence is interrupted, perhaps due to a delay in the Shuttle launch schedule.

In order for the station to be considered *viable*, three conditions must be satisfied : 1) the station must be controllable, both in terms of attitude and attitude rate, as well as altitude maintenance, 2) certain minimum power generation capabilities are achievable (whose magnitudes are flight dependent), and 3) crew survival is assured for the permanently manned configurations.

Objective

Define requirements to maintain a *viable* SSF if :

1) First Element Launch (FEL) is delayed, and/or
2) Nominal rendezvous sequence is interrupted

viable :

- controllable (altitude, attitude rates)
- minimal power requirements (flight dependent)
- assured crew survival (PMC and beyond)

Factors Which Impact SSF Viability

The first and most obvious factor which impacts SSF viability is the orbital lifetime and decay rate, which depends on both the atmospheric environment through which the vehicle flies, as well as the physical characteristics of the station itself, as manifested in the ballistic coefficient. Nominal sun–tracking of the photovoltaic arrays yields maximum power, but maximum drag, and hence, maximum decay rates and minimum orbital lifetimes. Feathered PV array configurations yield minimum drag and maximum lifetimes at the cost of reduced power generation capability. Alternate attitude profiles exist which may reduce both power capacity as well as power requirements.

The second factor which impacts SSF viability is the capacity to reboost the station into higher orbital altitudes. This factor depends on the station altitude, the amount of propellant available, and the reboost strategy or profile utilized following annunciation of the rendezvous interruption. The propellant availability depends on the time since the last refueling, the size of the propellant tanks, the specific impulse of the fuel, and how much of the propellant was utilized by the RCS attitude control system. Attitude control propellant usage depends on a variety of factors, including CMG capacity, and the degree of passive damping present.

Factors Which Impact SSF Viability

SSF Orbital Lifetime and Decay Rate

- Attitude / Ballistic Coefficient
  - nominal (max power ; max drag)
  - feathered (reduced power ; min drag)
  - gravity gradient stable (reduced power ; reduced power req'ts)
- Atmospheric Conditions

SSF Reboost Capacity

- Active control vs passive damping
- Amount of propellant available
  - specific impulse
  - tank size
  - time since last refuel
  - RCS attitude control requirements
- Altitude when rendezvous sequence interuption occurs
- Reboost profile following annunciation

Factors Which Impact SSF Viability (continued)

The amount of time of the launch slip, or rendezvous delay, obviously influences the long term survivability strategy of the space station. The eventual downtime may not even be known at the time of annunciation.

The presence of a crew for the permanently manned configurations also impacts station viability. Factors such as environmental control and life support system longevity, food, water and other logistic supplies, additional power required as a result of manned presence, and the means to safely exit the station for return to Earth must all be considered.

All of the factors listed must be analyzed when determining the viability of Space Station *Freedom* in the presence of a first element launch slip, or a nominal rendezvous sequence interrupt.

Factors Which Impact SSF Viability (continued)

Length of delayed rendezvous

- May be known or unknown at time of annunciation and reboost

Presence of a Crew (PMC and beyond)

- ECLSS lifetime
- Logistics requirements
- Power requirements

Assumptions

The following general assumptions and ground rules were adopted and preserved throughout the course of this study :

Hydrazine fuel was assumed (specific thrust = 230 seconds).

The current baseline tank capacity, consisting initially of four 4500 lb tanks, and eventually four 6720 lb tanks as the initial smaller tanks are replaced.

Relative to the first element launch delay analysis, two sigma atmospheric density profiles were assumed. The launch sequence was obtained from the December '89 stage summary databook, which assumed a first element launch on March 31, 1995, and a 28 flight assembly sequence leading to assembly complete configuration by June 15, 1999. It was further assumed that assembly flights 1 through 5 were assembled at an altitude of 220 Nm, while the remaining flights were assembled at 190 Nm.

With respect to the rendezvous sequence interrupt analysis, annunciation of the rendezvous delay was assumed to occur at the lowest possible altitude (i.e., at the nominal rendezvous assembly altitude, which is flight dependent). Furthermore, it was assumed that the length of the ensuing delay was unknown at the time of the annunciation.

Assumptions

Baseline Hydrazine propellant (Isp = 230 sec)

Baseline tank capacity
- First 4 RCS tanks @ 4500 lb each (18,000 lb total)
- Subsequent RCS tanks @ 6720 lb each (26,880 lb total)

FEL Assumptions

Based on 12/89 Stage Summary Databook
- FEL 3/31/95, AC 6/15/99, 28 flights
- Flights 1 through 5 assembled at 220 Nm
- Remaining flights assembled at 190 Nm

+2 sigma atmosphere predicts

Rendezvous Sequence Interrupt

Delayed rendezvous annunciation occurs at lowest possible altitude (nominal rendezvous – flight dependent)

Length of delay unknown at time of annunciation

Assumptions (concluded)

It was assumed that an Assured Crew Return Vehicle was present and functional from PMC and beyond.

The atmosphere model defined by CR BJ020361A was assumed, whereby a 2 sigma atmospheric density profile plus a +4 to –2 year solar cycle shift due to launch slip or atmospheric predict uncertainties may occur. The rendezvous altitude was constrained to meet the 90 day lifetime to 150 Nm requirement for configurations in which reboost is available, and a 180 day lifetime for configurations for which reboost is unavailable.

No SSF critical subsystem failures were assumed for this study. It was felt that the likelihood of additional problems beyond the rendezvous sequence interrupt was unrealistic, for example, simulating a CMG failure whereby more than nominal amounts of propellant are required for RCS attitude control.

Finally, it was assumed that once SSF viability was threatened, all ongoing experiment requirements for power, pointing, microgravity environment, etc. will be ignored in light of the greater concern over station viability. Similarly, the crew has the option to either begin conservation and ration procedures, and/or depart from the station in the ACRV.

Since each of the space station assembly configurations has different mass properties and will fly through different atmospheres, several configurations were studied. In addition, multiple reboost profiles with variable contingency delays were simulated, assuming multiple station attitudes where appropriate.

Assumptions (concluded)

ACRV present (PMC and beyond)

CR BJ020361A atmosphere and nominal rendezvous altitude:

- $+2\sigma$ *plus* -2 to $+4$ year solar cycle shift due to launch slip and/or atmosphere predict uncertainties
- 90 day lifetime to 150 Nm (reboost available)
  180 day lifetime to 150 Nm (reboost unavailable)

No SSF critical subsystem failures

Once SSF viability is threatened, assume :

- Experiment requirements are ignored (power, pointing, micro–g, etc.)
- Crew optionally departs and/or rations

Scope of Study

Multiple SSF Configurations

Multiple Reboost Profiles / Multiple Contingency Delays

Multiple Attitudes (when appropriate)

First Element Launch Delay

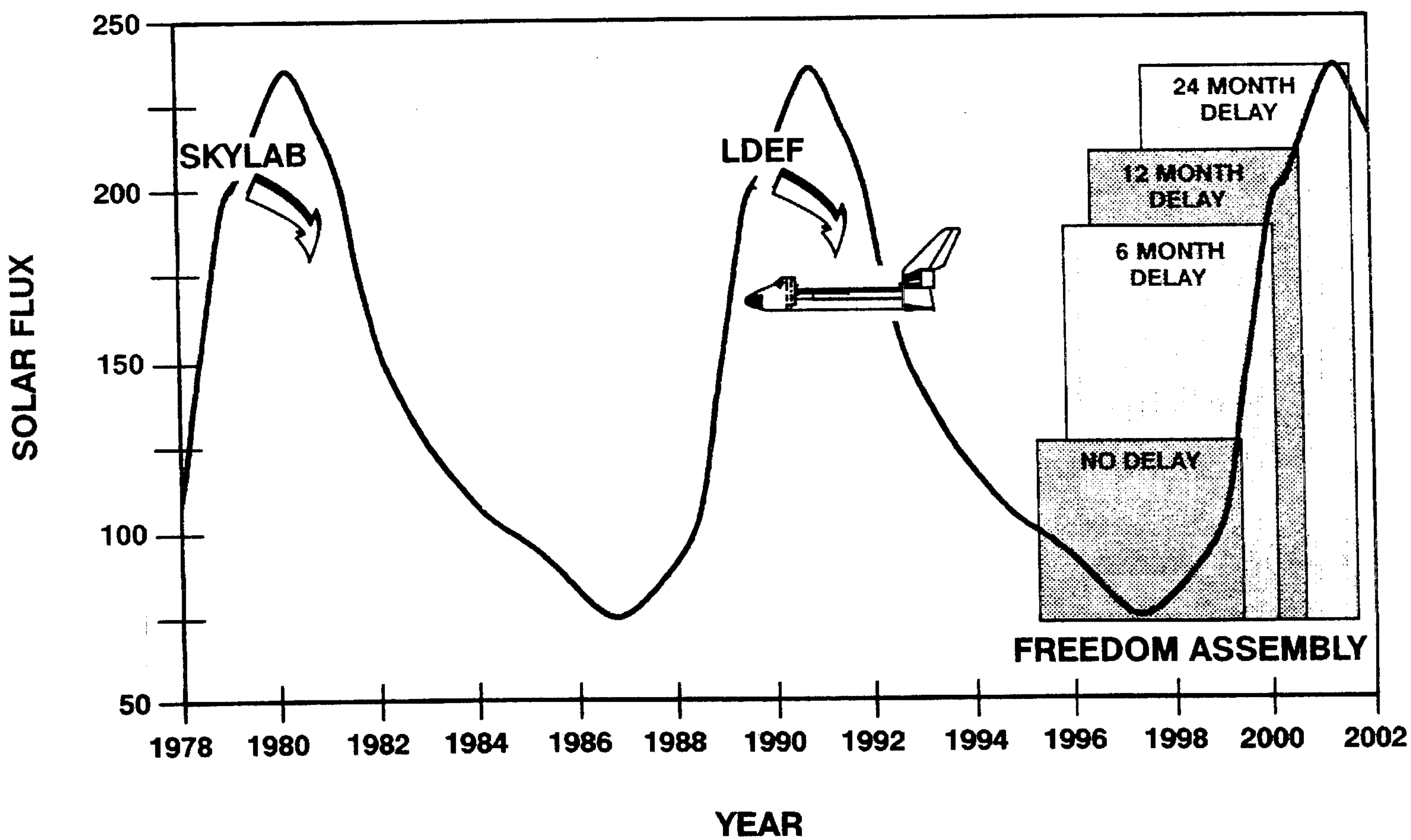
The remainder of the report is divided into two parts : the effects of first element launch delay on reboost and resupply, and the impact of an interruption to the nominal rendezvous sequence.

First Element Launch Delay

Solar Cycle Variation

The solar flux values that drive upper atmosphere density vary over an eleven year cycle. The peaks of the solar flux correspond to maximum atmospheric density for low Earth orbits. The rapid increase in flux just prior to the peak can be referred to as a "wall." This wall was responsible for the re–entry of Skylab in the late 70's and the rapid orbital decay of the LDEF just recently recovered by the shuttle. The next peak in the solar cycle occurs around the year 2001 – two years after the *scheduled* completion of the station. The shaded boxes represent the span of the assembly sequence. The box labeled 'No Delay' spans the lowest period of solar flux during the solar cycle. If the FEL date were to slip by 6,12 or 24 months, significant portions of the assembly sequence would occur during periods of higher atmospheric density thus increasing orbit decay rates and increasing reboost fuel requirements.

Solar Cycle Variation



Baseline Assembly Sequence Hydrazine Fuel History

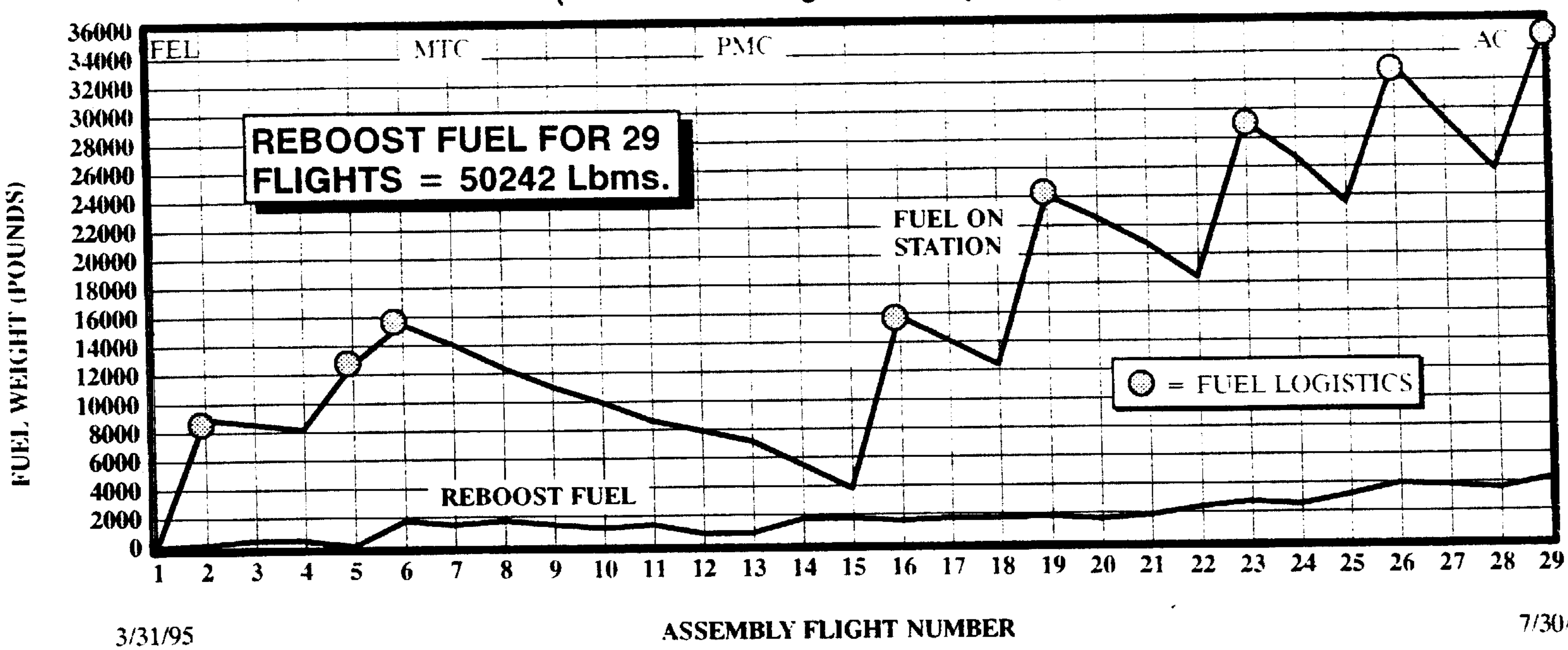
The baseline reboost fuel requirements are given as a function of assembly flight assuming a planned FEL date of 3/31/95. The top line indicates the amount of fuel present in the RCS tanks at each stage. The lower line indicates how much fuel is required for reboost. Circles represent stages where additional fuel was manifested. Station fuel reserves drop due to under 4,000 lbms at stage 15, but all stages have sufficient fuel to support the nominal assembly plan.

NASA — FREEDOM

Baseline Assembly Sequence Hydrazine Fuel History

First Element Launch on 3/31/95 as Planned

(Assumes +2 Sigma Atmosphere)



There is sufficient fuel on the station at all times during the assembly sequence to support the nominal assembly and reboost plan.

LaRC SSFO

basefuel

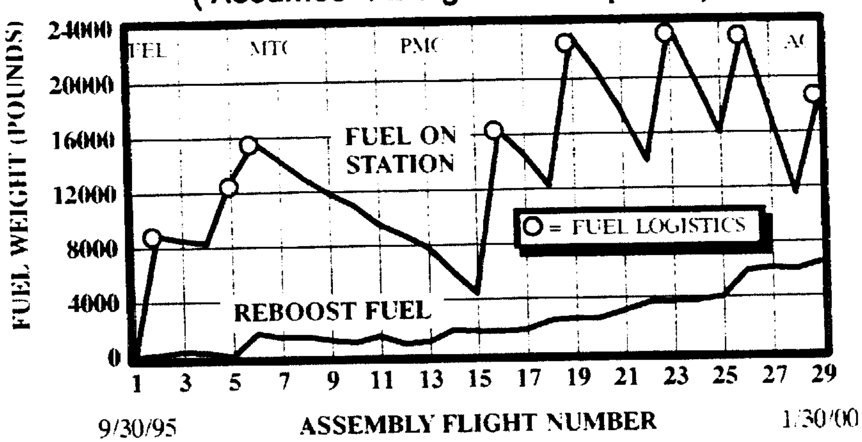
Sequence Fuel History for 6 & 12 month FEL Delays

A six month delay of FEL results in an additional reboost fuel requirement of 17,000 lbms during the assembly process. The increased drag near the end of the assembly sequence results in all stages past flight 17 violating the 90 days to 150 nmi lifetime requirement. A 12 month delay results in an additional requirement of 35,000 lbms more reboost fuel as compared to the baseline sequence. There would not be sufficient fuel to reboost the station at flights 25,27 and beyond thus risking station re–entry. All stages past flight 11 violate the 90 days to 150 nmi lifetime requirement.

NASA — FREEDOM

Sequence Fuel History for 6 & 12 Month FEL Delays

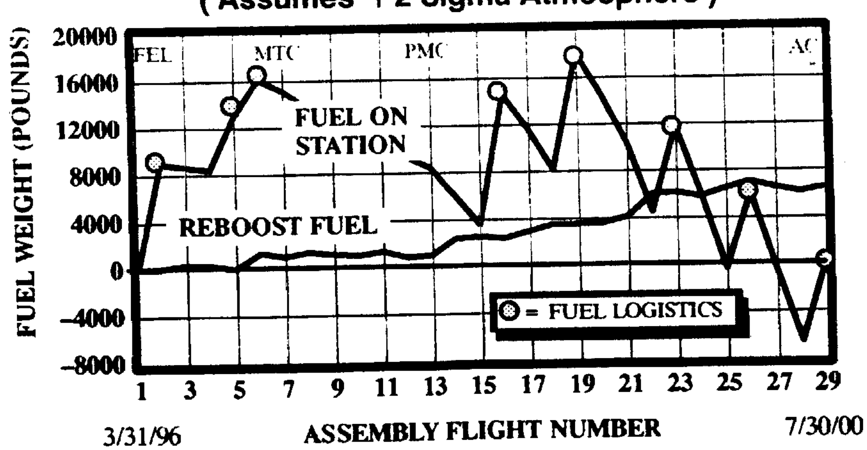
First Element Launch on 9/30/95
(Assumes +2 Sigma Atmosphere)



Six Month FEL Delay

- 67,000 pounds of fuel is required during the assembly sequence.
- Rendezvous altitude of 190 nmi violates the "90 day lifetime to 150 nmi" requirement for flights 6, 7, 8,14,17 and beyond.

First Element Launch on 3/31/96
(Assumes +2 Sigma Atmosphere)



Twelve Month FEL Delay

- Negative fuel margin occurs at flight 25, 27 and beyond.
- 85,000 pounds of fuel is required during the assembly sequence.
- Rendezvous altitude of 190 nmi violates the "90 day lifetime to 150 nmi" requirement for flights 6, 8, 11 and beyond.

LaRC SSFO

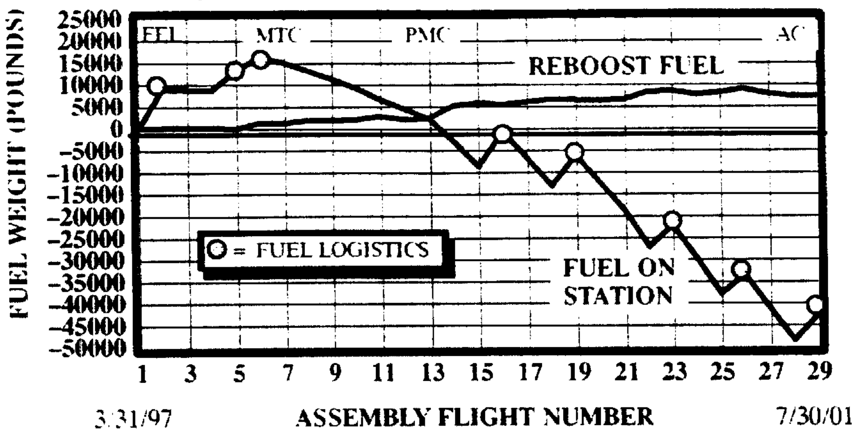
rb6&12

Sequence Fuel History for a 24 month FEL Delay

A 24 month delay of FEL results in a reboost fuel requirement of 128,000 lbms during the assembly process. There would not be sufficient fuel to reboost the station at flights 14 and beyond. All stages past flight 6 violate the 90 days to 150 nmi lifetime requirement. A 24 month delay of FEL was analyzed using a nominal predicted atmosphere in order to assess the sensitivity of reboost requirements with respect to atmospheric predictions. The results show sufficient fuel available throughout the assembly process except for stage 15. Assuming the nominal atmospheric predicts results in a nearly 50% reduction in calculated reboost fuel for the assembly sequence. These results indicate that using +2 sigma atmosphere predicts may be over conservative but in fact the last solar maximum had actual flux values that *exceeded* the +2 sigma predictions.

Sequence Fuel History for a 24 Month FEL Delay

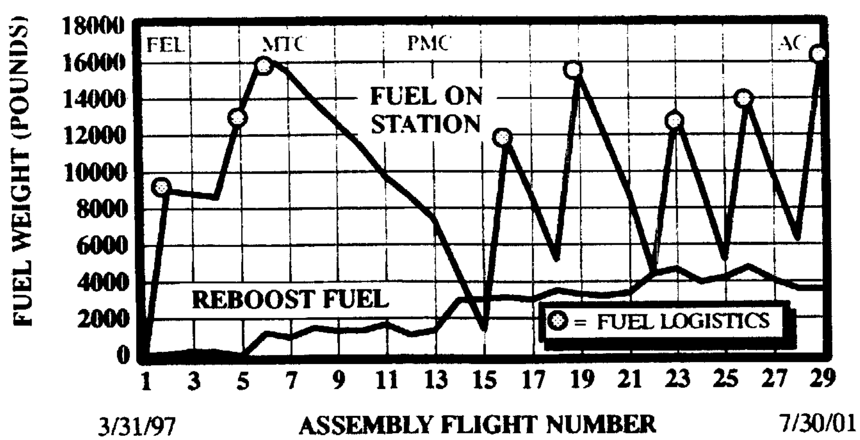
First Element Launch on 3/31/97
(Assumes +2 Sigma Atmosphere)



24 Month FEL Delay

- Negative fuel margin occurs at flight 14 and beyond.
- 128,000 pounds of fuel is required during the assembly sequence.
- Rendezvous altitude of 190 nmi violates the "90 days lifetime to 150 nmi" requirement for flights 6 and beyond.

First Element Launch on 3/31/97 (Nominal Atmosphere)



24 Month FEL Delay - Nominal Atmosphere

- 69,000 pounds of fuel is required during the assembly sequence.
- Nominal atmosphere results in a nearly 50% reduction in the calculated reboost fuel for the assembly sequence. These numbers reflect the uncertainty in atmospheric density prediction.

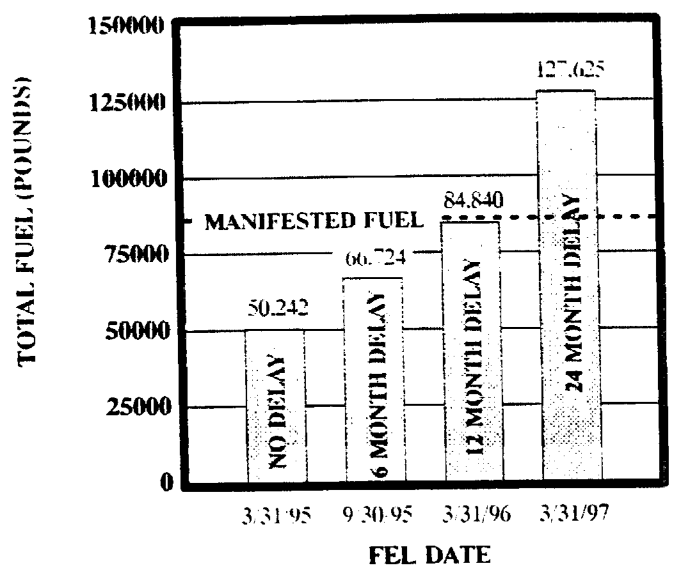
Reboost Fuel & Orbit Lifetime Impacts due to FEL Delay

The chart on the left indicates total assembly sequence reboost fuel required for the selected FEL delays. The dashed line represents the total amount of reboost resupply fuel manifested on the shuttle during the assembly sequence. Sufficient fuel is available for the zero and six month delay cases. The 12 month delay case would require some optimization and rescheduling of logistics flights in order to avoid fuel shortages. The 24 month delay case requires much more reboost fuel than is supplied via orbiter logistics. The chart on the right indicates the number of flights that violate the 90 days to 150 nmi lifetime requirement for each of the selected FEL delays. Each of the four delay scenarios had over ten flights that did not meet the requirement.

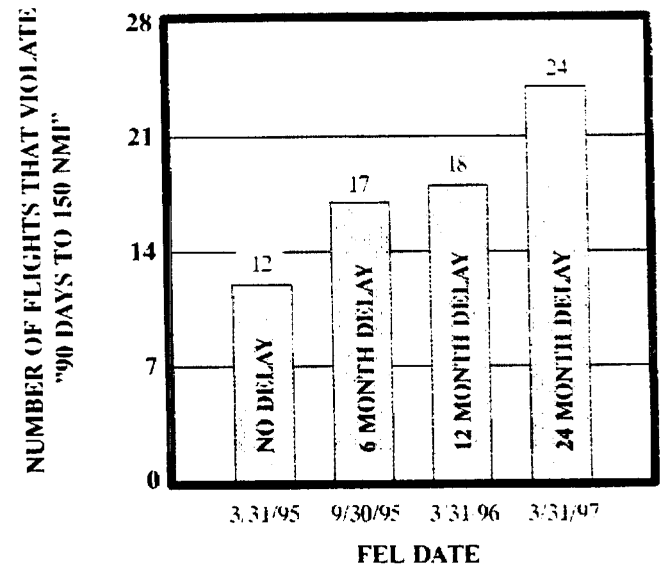
NASA — FREEDOM

Reboost Fuel and Orbit Lifetime Impacts Due to FEL Delay

Total Assembly Sequence Reboost Fuel vs FEL Launch Delay



Number of Flights That Violate "90 Days to 150 NMI" vs FEL Launch Delay



Delays in the assembly sequence can result in significant increases in reboost fuel requirements and the number of flights with unacceptable orbit lifetimes.

LaRC SSFO

numsum

Possible Solutions / Impacts

The reboost fuel shortages and orbit lifetime problems due to a 24 month FEL delay can be minimized. Additional STS fuel logistics flights can be inserted into the assembly sequence thus reducing the fuel shortage. Larger capacity fuel tanks could be used but this would also add flights to the assembly sequence since the larger tanks would displace other space station components in the orbiter cargo bay. The assembly altitude can be raised so that the station flies through a less dense atmosphere thus reducing reboost fuel requirements an increasing orbit lifetimes.

Possible Solutions / Impacts

Additional STS logistics flights:
- Stretches out assembly sequence.
- Does not address 90 day lifetime problems.

Larger capacity fuel tanks:
- Requires some off loading of other elements, (leading to additional flights or the use of ASRMs).
- Does not address 90 day lifetime problems.

Raise Assembly Altitude:
- Requires some off loading of assembly elements, (leading to additional flights or the use of ASRMs).
- Increases orbit lifetime to 150 nmi.

Assembly Sequence Fuel History – All flights at 220 Nautical Miles

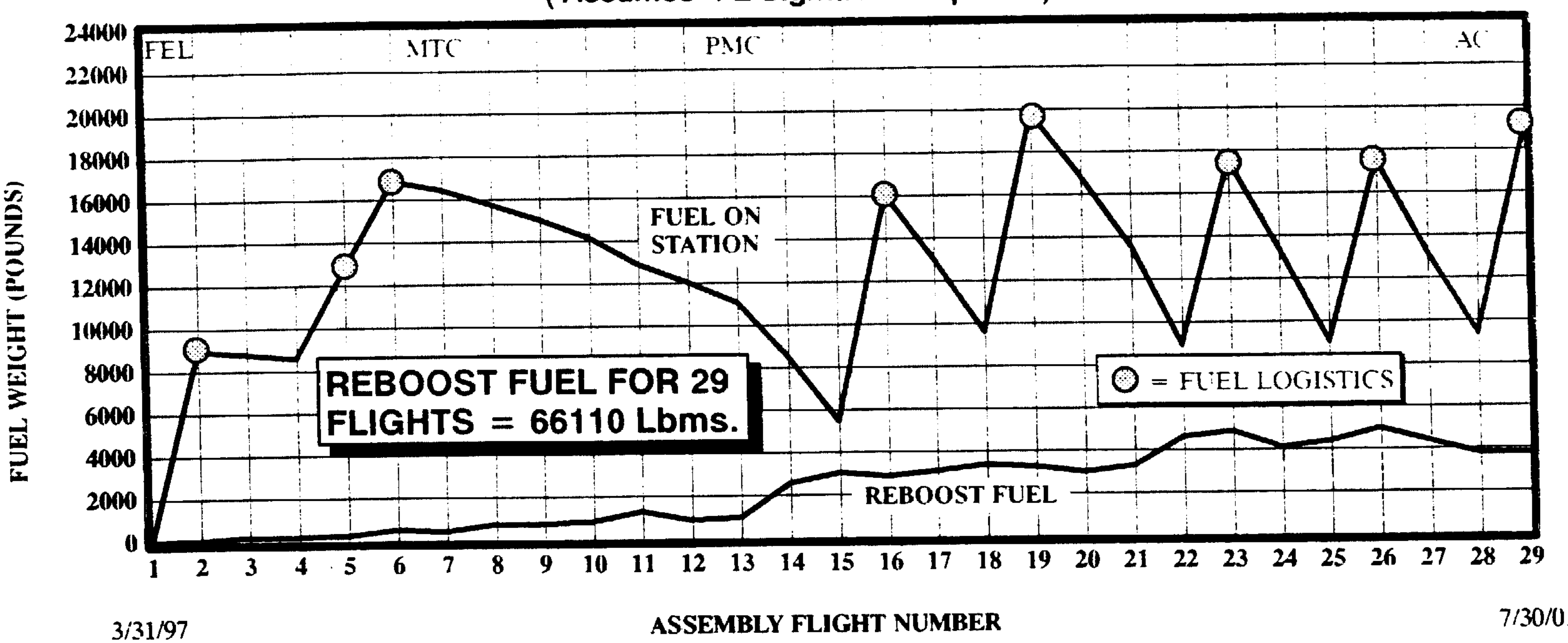
Reboost fuel requirements were calculated assuming all station/orbiter rendezvous were performed at 220 nmi with a FEL delay of 24 months. Sufficient reboost fuel is always available and a surplus of fuel is left over at the end of the assembly sequence.

NASA — FREEDOM

Assembly Sequence Fuel History – All Flights at 220 NMI

First Element Launch on 3/31/97 –24 Month Delay

(Assumes +2 Sigma Atmosphere)



There is sufficient fuel on the station at all times during the assembly sequence (with the exception of FEL) to reboost the station for its next rendezvous.

Assembly Sequence Summary

The first half of the assembly sequence prior to the PMC stage is relatively insensitive to FEL delays with respect to reboost fuel since that portion of the sequence occurs during the lowest part of the solar cycle for the FEL delays studied. There is not sufficient reboost fuel after PMC for 12 and 24 month FEL delays. If a 24 month interruption in the assembly sequence were to occur somewhere prior to PMC, the remainder of the sequence would require higher STS rendezvous altitudes to reduce reboost requirements and provide sufficient orbit lifetimes. If ASRMs are not available then additional STS flights would have to be added to the assembly sequence.

Assembly Sequence Summary

- For FEL thru PMC, launch delays have a minor impact on reboost requirements.

- Insufficient reboost fuel is available post PMC for 12 and 24 month launch delays occurring prior to PMC.

- If a 24 month interruption were to occur somewhere prior to PMC in the assembly sequence, the remainder of the sequence would require higher STS delivery and rendezvous altitudes to reduce reboost requirements and provide sufficient orbit lifetime.

If ASRMs are not available then additional flights would have to be added to the sequence.

Assembly Sequence Configuration Characteristics and Reboost Fuel Requirements

The following tables enumerate the individual flight configuration characteristics and fuel requirements for the reboost cases previously discussed in this report.

Assembly Sequence Configuration Characteristics and Reboost Fuel Requirements

(BASELINE ASSEMBLY SEQUENCE REBOOST HISTORY (FROM STAGE SUMMARY DATABOOK - 12 89)

FLIGHT NUMBER	FLIGHT NAME	LAUNCH DATE	TANK CAPACITY	REBOOST FUEL	RESUPPLY FUEL	FUEL IN TANKS	M/CD*A LBS/FT**2	M/CD*A KG/M**2	MASS POUNDS	MASS KG	AREA METERS**2	BASELINE LAUNCH DATES LATEST ATMOSPHERE: LAUNCH DATE	REBOOST FUEL	FUEL IN TANKS
1	MB-1,FEL	3/31/95	0	0	0	0	20.0	97.6	28593	12967	58	3/31/95	0	0
2	MB-2	6/15/95	9000	160	9000	8840	12.0	58.6	52638	23872	177	6/15/95	102	8898
3	MB-3	8/31/95	9000	325	0	8515	5.1	24.9	76055	34492	602	8/31/95	400	8498
4	MB-4	11/15/95	9000	325	0	8190	7.1	34.7	105408	47804	600	11/15/95	350	8148
5	MB-5	1/31/96	13500	575	4500	12115	6.3	30.8	129412	58690	830	1/31/96	0	12648
6	MB-6	3/31/96	18000	1450	4500	15165	4.6	22.5	159406	72293	1400	3/31/96	1700	15448
7	MB-7,MTC	6/15/96	18000	1375	0	13790	6.1	29.8	192888	87478	1277	6/15/96	1400	14048
8	OF-1	8/30/96	18000	1350	0	12440	6.3	30.8	210095	95281	1347	8/30/96	1650	12398
9	MB-8	11/15/96	18000	1275	0	11165	7.9	38.6	241295	109431	1234	11/15/96	1370	11028
10	MB-9	1/31/97	18000	1000	0	10165	9.1	44.4	277066	125654	1230	1/31/97	1105	9923
11	OF-2	3/31/97	18000	1250	0	8915	9.6	46.9	299665	135902	1261	3/31/97	1340	8583
12	MB-10	6/15/97	18000	825	0	8090	10.1	49.3	330835	150039	1323	6/15/97	710	7873
13	L-1,PMC	7/30/97	18000	875	0	7215	10.8	52.7	364735	165413	1364	7/30/97	745	7128
14	MB-11	9/15/97	18000	1500	0	5715	6.6	32.2	398177	180579	2437	9/15/97	1650	5478
15	L-2	10/31/97	18000	1550	0	4165	6.6	32.2	410552	186191	2513	10/31/97	1700	3778
16	L-3	12/15/97	22440	1625	13440	15980	6.9	33.7	440382	199720	2578	12/15/97	1490	15728
17	MB-12	2/1/98	22440	1500	0	14480	7.8	38.1	475143	215484	2461	2/1/98	1690	14038
18	L-4	3/15/98	22440	1650	0	12830	7.9	38.6	475143	215484	2429	3/15/98	1670	12368
19	L-5	4/30/98	26880	1750	13440	24520	8.0	39.1	494612	224314	2497	4/30/98	1750	24058
20	MB-13	6/15/98	26880	1800	0	22720	8.4	41.0	529373	240078	2546	6/15/98	1550	22508
21	L-6	7/30/98	26880	2000	0	20720	8.6	42.0	531059	240843	2494	7/30/98	1810	20698
22	MB-14	9/15/98	26880	2050	0	18670	8.9	43.4	551731	250218	2504	9/15/98	2350	18348
23	L-7	10/31/98	26880	2200	13440	29910	8.7	42.5	551731	250218	2562	10/31/98	2700	29088
24	L-8	12/15/98	26880	2500	0	27410	8.7	42.5	551731	250218	2562	12/15/98	2460	26628
25	OF-3	1/31/99	26880	2650	0	24760	9.3	45.4	569821	258422	2475	1/31/99	3150	23478
26	L-9	3/15/99	26880	3100	13440	35100	9.2	44.9	569821	258422	2502	3/15/99	3900	33018
27	L-10	4/30/99	26880	3375	0	31725	9.2	44.9	569821	258422	2502	4/30/99	3750	29268
28	OF-4,AC	6/15/99	26880	3725	0	28000	9.6	46.9	586203	265852	2466	6/15/99	3525	25743
29	L-11	7/30/99	26880	3700	13440	37740	9.7	47.4	586203	265852	2441	7/30/99	4225	34958

TOTAL FUEL = 47460

TOTAL FUEL = 50242

Assembly Sequence Reboost Requirements for 6 & 12 Month FEL Delays

FLIGHT INFORMATION			6 MONTH DELAY			12 MONTH DELAY		
FLIGHT NUMBER	FLIGHT NAME	RESUPPLY FUEL	LAUNCH DATE	REBOOST FUEL	FUEL IN TANKS	LAUNCH DATE	REBOOST FUEL	FUEL IN TANKS
1	MB-1.FEL	0	9/31/95	0	0	3/31/96	0	0
2	MB-2	9000	12/15/95	134	8866	6/15/96	70	8930
3	MB-3	0	2/31/96	340	8526	8/31/96	300	8630
4	MB-4	0	5/15/96	240	8286	11/15/96	240	8390
5	MB-5	4500	7/31/96	0	12786	1/31/97	0	12890
6	MB-6	4500	9/31/96	1650	15636	3/31/97	1325	16065
7	MB-7,MTC	0	12/15/96	1320	14316	6/15/97	975	15090
8	OF-1	0	2/30/97	1350	12966	8/30/97	1350	13740
9	MB-8	0	5/15/97	1110	11856	11/15/97	1160	12580
10	MB-9	0	7/31/97	925	10931	1/31/98	1025	11555
11	OF-2	0	9/31/97	1390	9541	3/31/98	1375	10180
12	MB-10	0	12/15/97	800	8741	6/15/98	845	9335
13	L-1,PMC	0	1/30/98	930	7811	7/30/98	970	8365
14	MB-11	0	3/15/98	1725	6086	9/15/98	2350	6015
15	L-2	0	4/31/98	1650	4436	10/31/98	2500	3515
16	L-3	13440	6/15/98	1600	16276	12/15/98	2365	14590
17	MB-12	0	8/1/98	1725	14551	2/1/99	2940	11650
18	L-4	0	9/15/98	2360	12191	3/15/99	3525	8125
19	L-5	13440	10/30/98	2500	23131	4/30/99	3500	18065
20	MB-13	0	12/15/98	2500	20631	6/15/99	3550	14515
21	L-6	0	1/30/99	3025	17606	7/30/99	4075	10440
22	MB-14	0	3/15/99	3625	13981	9/15/99	5950	4490
23	L-7	13440	4/31/99	3675	23746	10/31/99	6150	11780
24	L-8	0	6/15/99	3750	19996	12/15/99	5750	6030
25	OF-3	0	7/31/99	4000	15996	1/31/00	6425	-395
26	L-9	13440	9/15/99	5850	23586	3/15/00	7000	6045
27	L-10	0	10/30/99	6100	17486	4/30/00	6500	-455
28	OF-4,AC	0	12/15/99	5975	11511	6/15/00	6150	-6605
29	L-11	13440	1/30/00	6475	18476	7/30/00	6475	360
			TOTAL FUEL =	66724		TOTAL FUEL =	84840	

Assembly Sequence Reboost Requirements for a 24 Month FEL Delay

FLIGHT INFIRMATION				24 MONTH DELAY			24 MONTH DELAY ALL FLIGHTS AT 220 NMI			24 MONTH DELAY NOMINAL ATMOSPHERE		
FLIGHT NUMBER	FLIGHT NAME	RESUPPLY FUEL	TANK CAPACITY	LAUNCH DATE	REBOOST FUEL	FUEL IN TANKS	LAUNCH DATE	REBOOST FUEL	FUEL IN TANKS	LAUNCH DATE	REBOOST FUEL	FUEL IN TANKS
1	MB-1.FEL	0	0	3/31/97	0	0	3/31/97	0	0	3/31/97	0	0
2	MB-2	9000	9000	6/15/97	45	8955	6/15/97	45	8955	6/15/97	40	8960
3	MB-3	0	9000	8/31/97	175	8780	8/31/97	175	8780	8/31/97	170	8790
4	MB-4	0	9000	11/15/97	195	8585	11/15/97	195	8585	11/15/97	165	8625
5	MB-5	4500	13500	1/31/98	0	13085	1/31/98	245	12840	1/31/98	0	13125
6	MB-6	4500	18000	3/31/98	1350	16235	3/31/98	485	16855	3/31/98	1200	16425
7	MB-7.MTC	0	18000	6/15/98	1220	15015	6/15/98	410	16445	6/15/98	975	15450
8	OF-1	0	18000	8/30/98	1900	13115	8/30/98	725	15720	8/30/98	1475	13975
9	MB-8	0	18000	11/15/98	1790	11325	11/15/98	730	14990	11/15/98	1300	12675
10	MB-9	0	18000	1/31/99	2075	9250	1/31/99	825	14165	1/31/99	1300	11375
11	OF-2	0	18000	3/31/99	2775	6475	3/31/99	1275	12890	3/31/99	1650	9725
12	MB-10	0	18000	6/15/99	2000	4475	6/15/99	850	12040	6/15/99	1075	8650
13	L-1.PMC	0	18000	7/30/99	2300	2175	7/30/99	975	11065	7/30/99	1300	7350
14	MB-11	0	18000	9/15/99	5100	-2925	9/15/99	2550	8515	9/15/99	2950	4400
15	L-2	0	18000	10/31/99	5850	-8775	10/31/99	3025	5490	10/31/99	3025	1375
16	L-3	13440	22440	12/15/99	5400	-735	12/15/99	2850	16080	12/15/99	3125	11690
17	MB-12	0	22440	2/1/00	6025	-6760	2/1/00	3075	13005	2/1/00	3000	8690
18	L-4	0	22440	3/15/00	6500	-13260	3/15/00	3375	9630	3/15/00	3475	5215
19	L-5	13440	26880	4/30/00	6325	-6145	4/30/00	3250	19820	4/30/00	3300	15355
20	MB-13	0	26880	6/15/00	6225	-12370	6/15/00	3000	16820	6/15/00	3200	12155
21	L-6	0	26880	7/30/00	6550	-18920	7/30/00	3275	13545	7/30/00	3350	8805
22	MB-14	0	26880	9/15/00	8250	-27170	9/15/00	4600	8945	9/15/00	4375	4430
23	L-7	13440	26880	10/31/00	8475	-22205	10/31/00	4850	17535	10/31/00	4625	13245
24	L-8	0	26880	12/15/00	7700	-29905	12/15/00	4100	13435	12/15/00	3925	9320
25	OF-3	0	26880	1/31/01	8025	-37930	1/31/01	4375	9060	1/31/01	4150	5170
26	L-9	13440	26880	3/15/01	8950	-33440	3/15/01	4975	17525	3/15/01	4750	13860
27	L-10	0	26880	4/30/01	7850	-41290	4/30/01	4350	13175	4/30/01	4025	9835
28	OF-4,AC	0	26880	6/15/01	7200	-48490	6/15/01	3750	9425	6/15/01	3550	6285
29	L-11	13440	26880	7/30/01	7375	-42425	7/30/01	3775	19090	7/30/01	3525	16200
				TOTAL FUEL =	127625		TOTAL FUEL =	66110		TOTAL FUEL =	69000	

ORIGINAL PAGE IS OF POOR QUALITY

Rendezvous Sequence Interrupt

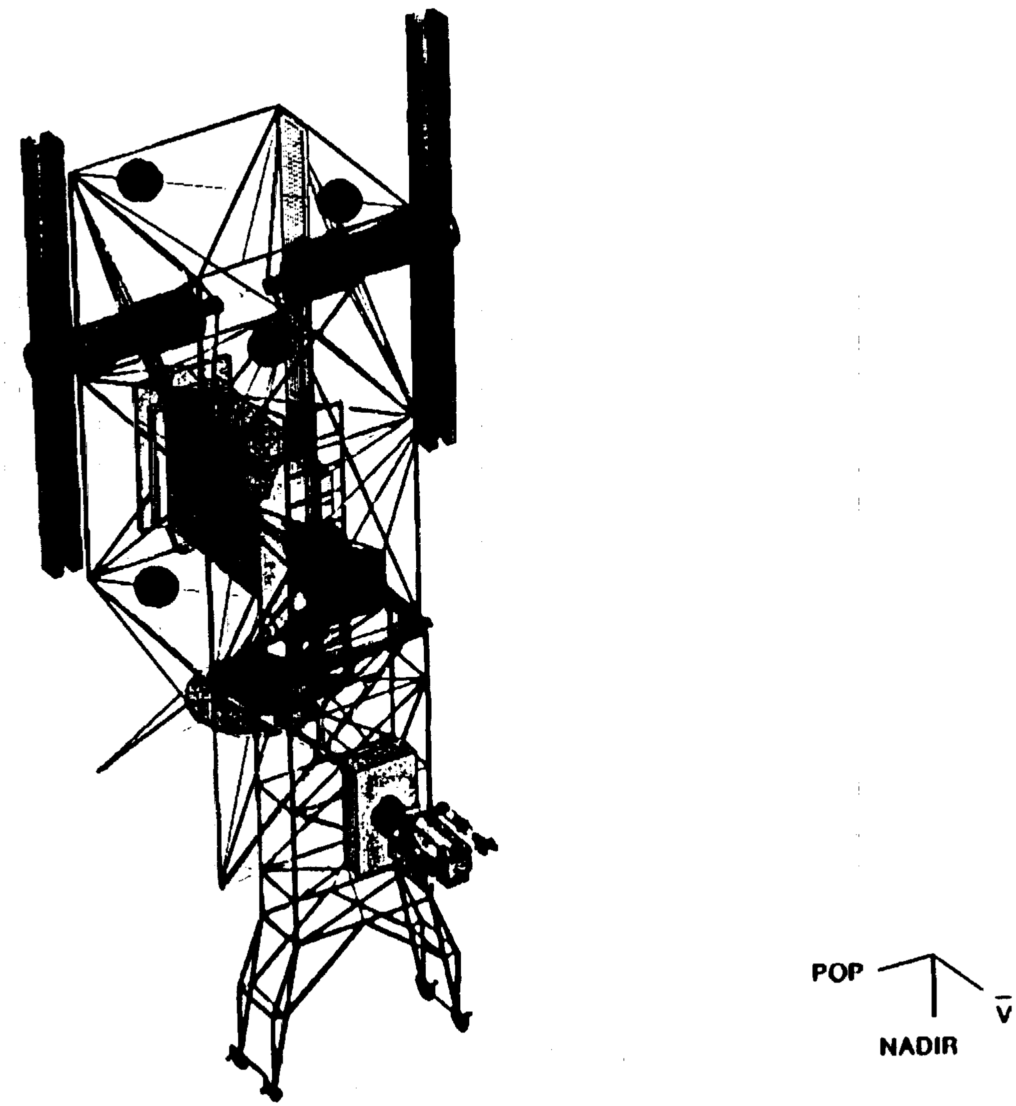
The second half of the report discusses the impact of an interruption to the nominal rendezvous sequence on Space Station *Freedom* viability.

Rendezvous Sequence Interrupt

MB1 – First Element Launch

The first configuration analyzed was MB1. The figure opposite illustrates the configuration geometry and nominal (gravity gradient) flight attitude. Note that the solar arrays are not deployed; furthermore, the vehicle is not actively controlled, but 5 passive magnetic dampers are used to damp out attitude rates.

MB1 - First Element Launch



LaRC SSFO
October 30, 1990

MB–1 Orbital Lifetime Characteristics

Since the passive MB–1 has no reboost capability, the orbital lifetime characteristics are presented. On the left side of the chart is a plot of orbit lifetime (in days) starting from an assembly altitude of 250 Nm. The vertical axis represents altitude in Nm. Four cases are considered : 1) nominal launch date (March 31, 1995), nominal atmosphere, 2) Nominal launch date, 2 sigma atmosphere, 3) slipped launch date*, nominal atmosphere, and 4) slipped launch date, 2 sigma atmosphere. As can be seen from the plot, the case 1 simulation lifetime is well in excess of 6 years. The impact of a 2 sigma atmosphere alone (case 2) reduces the orbit lifetime of MB–1 to 5 years starting from an altitude of 250 Nm. The impact of a worst case slipped launch date alone (case 3) reduces the orbit lifetime of MB–1 to approximately 3 years starting from an altitude of 250 Nm. The combination of slipped launch date and 2 sigma atmospheric density profile shortens the MB–1 lifetime to less than 2 years.

The table on the right side of the chart presents similar data in a somewhat different format. The same 4 cases appear across the top of the table, while each row represents a different starting altitude. The numeric results appearing in the table represent the lifetime (in months) for each of the 4 cases studied starting at each of the 4 initial altitudes simulated. The shaded boxes represent those combinations of atmosphere assumptions and initial altitudes which result in orbital lifetimes of less than 2 years (note : the PDRD requirement for orbital lifetime to 150 Nm for passive vehicles is 180 days). Thus, MB–1 must be assembled at an altitude *above* 220 Nm to assure a 2 year lifetime if launched on the nominal assembly date (March 31, 1995). In the event of a slipped launch date, MB–1 must be assembled at an altitude above 250 Nm to assure a 2 year lifetime. A 220 Nm assembly altitude will, however, assure that the 180 day lifetime requirement is met.

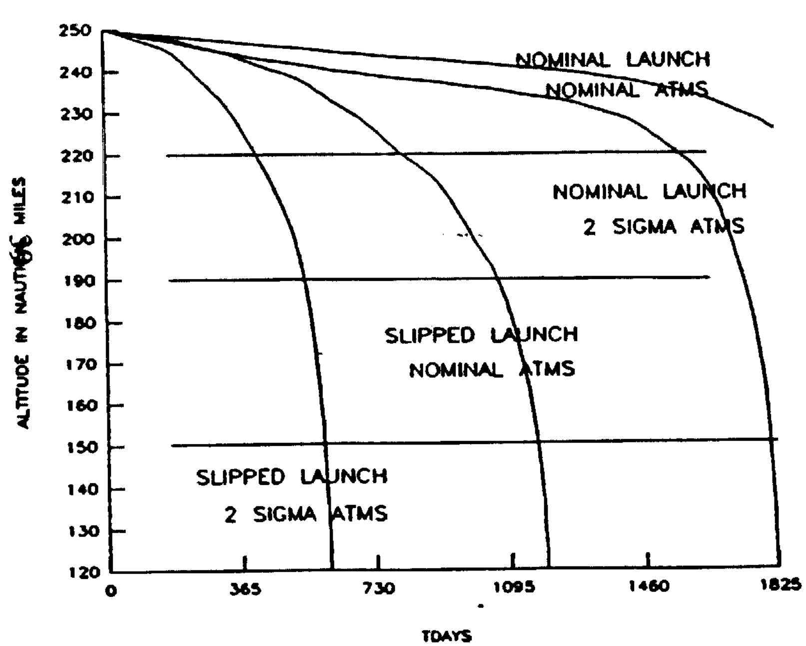
* CR BJ020361A

MB–1
Orbital Lifetime Characteristics
(no re–boost capability)

Ballistic Coefficient = 91.6

Nominal Launch Date = March 31, 1995

HEIGHT OF PERIGEE ABOVE EARTH VS TIME



LIFETIME UNTIL 150 Nm (MONTHS)

Altitude	Nominal Assembly Date		Slipped Assembly Date	
	Nominal Atmosphere	2 sigma Atmosphere	Nominal Atmosphere	2 sigma Atmosphere
250	73	58	38	19
235	58	46	25.5	14
220	35	21.5	17.5	10
190	7.5	5	6	4

MB–1 must be assembled above an altitude of 220 Nm to assure a 2 year lifetime if launched on nominal assembly date.

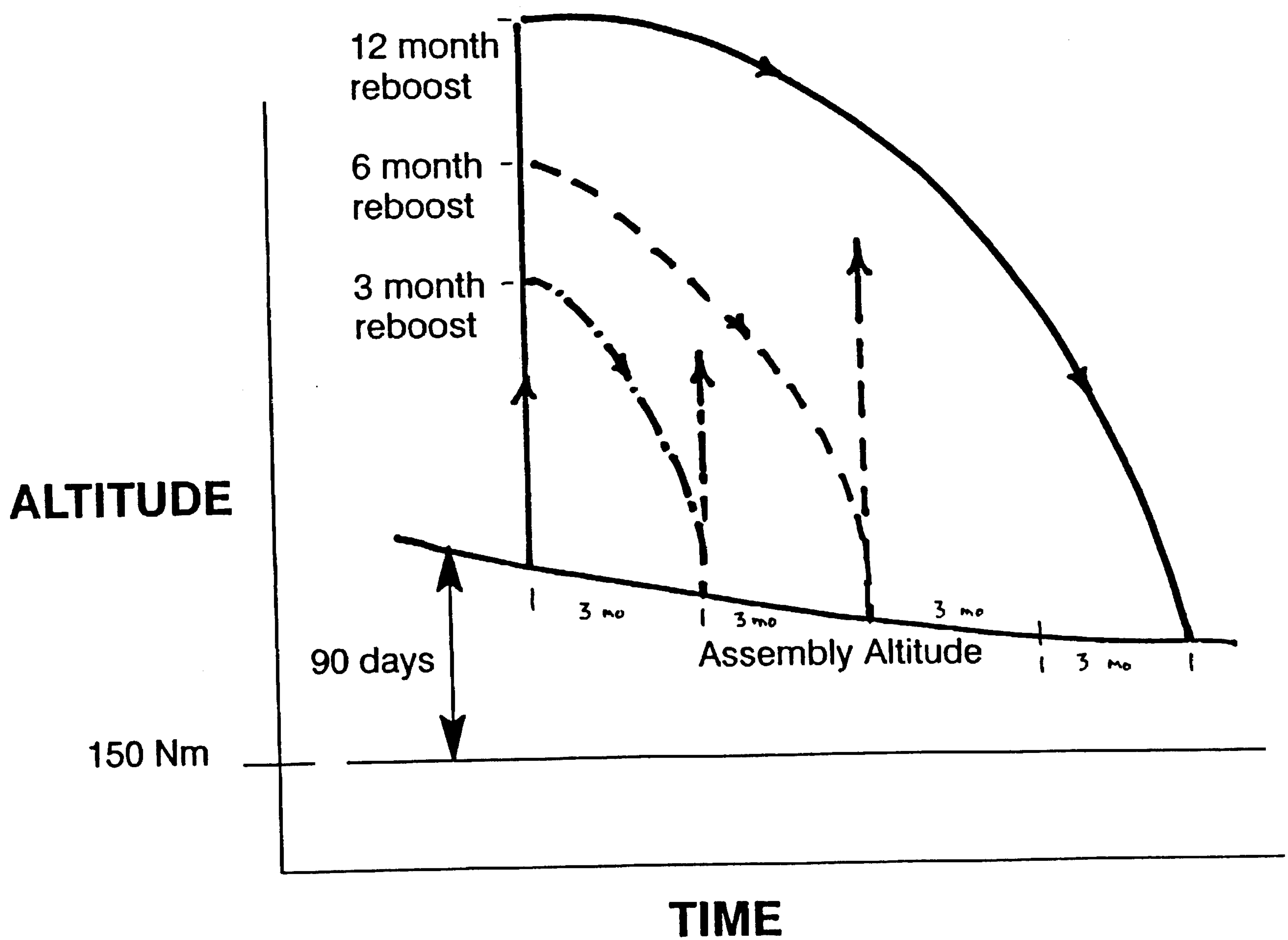
In the event of a slipped launch date, MB–1 must be assembled at an altitude above 250 Nm to assure a 2 year lifetime.

Typical Reboost Profile

The figure opposite depicts 3 superimposed typical reboost profiles plotted as altitude vs time. This particular figure shows the reboost altitude profile(s) necessary to insure a 1 year lifetime *above* a 90 day lifetime above 150 Nm altitude. In other words, it shows the altitude profile to which the station must be reboosted such that 12 months later, the station still has a 90 day lifetime to decay to 150 Nm.

Three profiles are illustrated. The solid line illustrates one 12 month reboost. In other words, it (generically) shows the altitude to which the station must be reboosted *once* in order to achieve the 12 month lifetime. The dashed line shows a two reboost profile. Here the initial reboost is to a lower altitude than the 12 month reboost since the lifetime is only 6 months; however, a *second* reboost must be performed 6 months later in order to obtain the required 12 month lifetime. Finally, the dash–dot plot illustrates a *four* reboost scenario whereby the 12 month lifetime is achieved in 3 month increments.

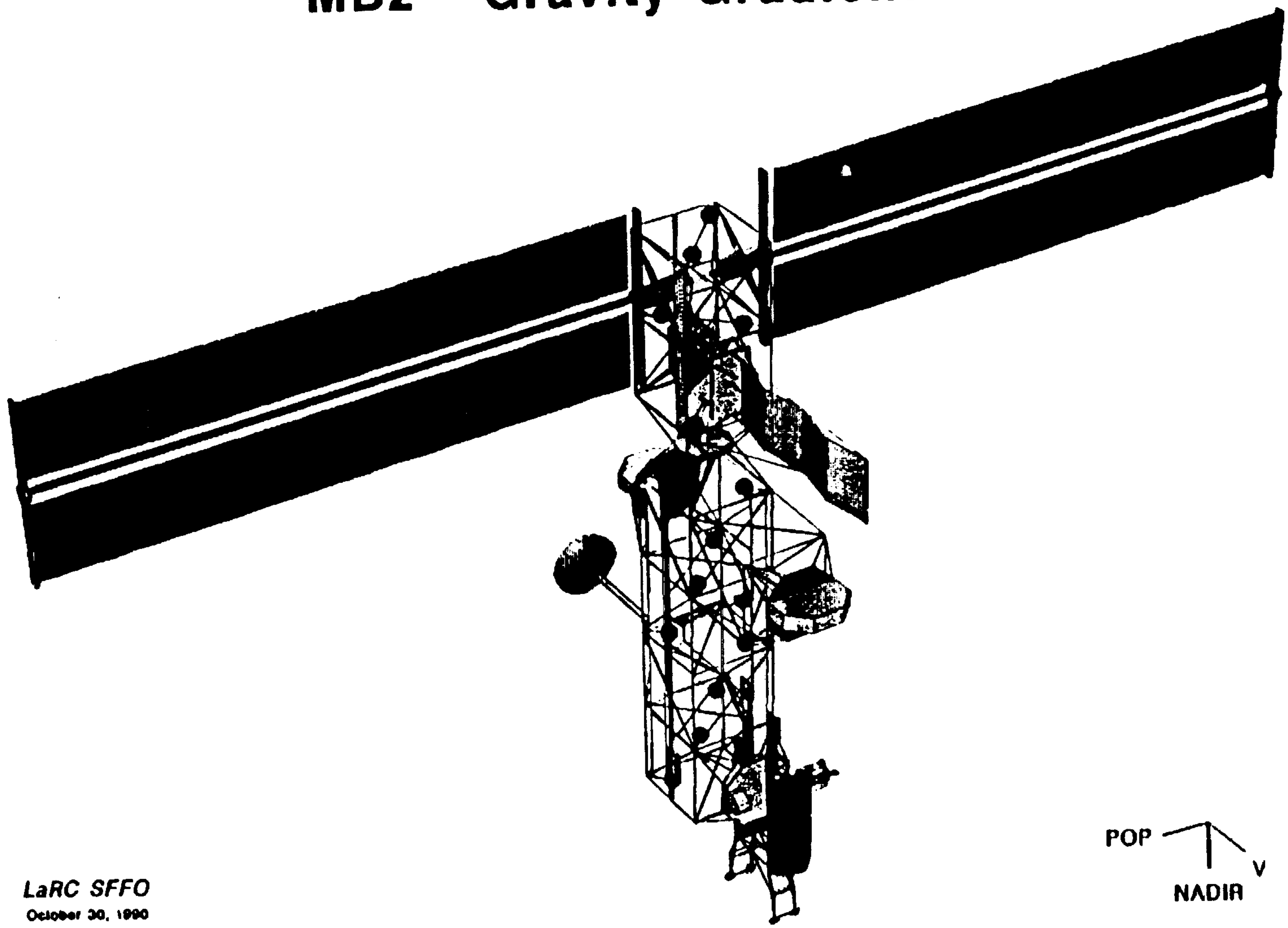
Typical Reboost Profile



MB2 – Gravity Gradient

The next configuration analyzed was the second assembly flight – MB2. Note from the figure that the photovoltaic arrays, which significantly increase the drag area (and hence, reduce the ballistic coefficient) are assumed to be deployed. It is further assumed that Control Moment Gyroscope attitude control is *not* available.

MB2 - Gravity Gradient



LaRC SFFO
October 30, 1990

MB–2 Gravity Gradient Results Summary

The Table opposite summarizes the results of the MB–2 contingency reboost and resupply analyses performed. The nominal assumed launch date was June 15, 1995. The nominal rendezvous altitude (to achieve a 90 day lifetime to 150 Nm in the presence of a 2 sigma atmosphere) was 224 Nm. The initial lifetime from 224 Nm to 150 Nm extends to 182 days for feathered PV arrays. The tank capacity is 9000 lb of fuel, with an expected fuel availability of 8840 lb remaining according to the 11/89 Level 2 Stage Summary Databook..

The table is divided into 2 parts. The upper half summarizes the results for a sun–tracking PV array mode, while the bottom half summarizes feathered PV array results. The remainder of the table lists the fuel requirements (reboost *and* attitude control) for various combinations of downtimes and reboost intervals. For the two year maximum downtime or scheduled rendezvous interruption studied, 2 twelve month reboosts require 4000 lb of hydrazine, and an additional 292 lb for RCS attitude control – within the advertised fuel capacity available. Note that the 12 month reboost takes the station up to an altitude of 280 Nm! The same 2 year downtime requires more fuel if performed through a series of eight 3 month reboosts since more of the decay time is spent in the lower, and thus denser, atmosphere. Nevertheless, even the 3 month reboost interval scenario fuel requirements are still less than the fuel available. Note that the 6 month downtime – 12 month reboost combination actually requires fuel to perform a de–boost. This scenario might occur if a 1 year downtime is anticipated, but only a 6 month downtime occurs.

As would be expected, the fuel requirements for the feathered MB–2 results are lower than the sun–tracking results since the ballistic coefficient is higher, and hence, the orbit decay rate is smaller.

Configuration : **MB-2**
(gravity gradient)
Nominal Launch Date : June, 1995
Nominal Rendezvous Altitude : 224 Nm

Lifetime to 150 Nm : 90 days (sun-tracking);
182 days (feathered)
Tank Capacity : 9000 lb
Nominal Fuel available [1] : 8840 lb

Flight mode	Reboost Interval (months)	Fuel Requirements (lb)		
		6 month downtime 6-15-1999	1 year downtime 6-15-1999	2 year downtime 6-15-1999
Sun-tracking	3	1300 + 73	3100 + 146	7500 + 292
(BC = 19.1)	6	1100 + 73	2400 + 146	5700 + 292
0.4 lb fuel/day req'd for attitude control	12	3000 + 73 *	1700 + 146	4000 + 292 280 Nm
	3	600	1500	3700
Feathered (BC = 51.8)	6	500	1250	3100
no fuel req'd to maintain attitude	12	1700 *	1000	2400

1. Level 2 Stage Summary Databook - 11/89

* *de-boost required*

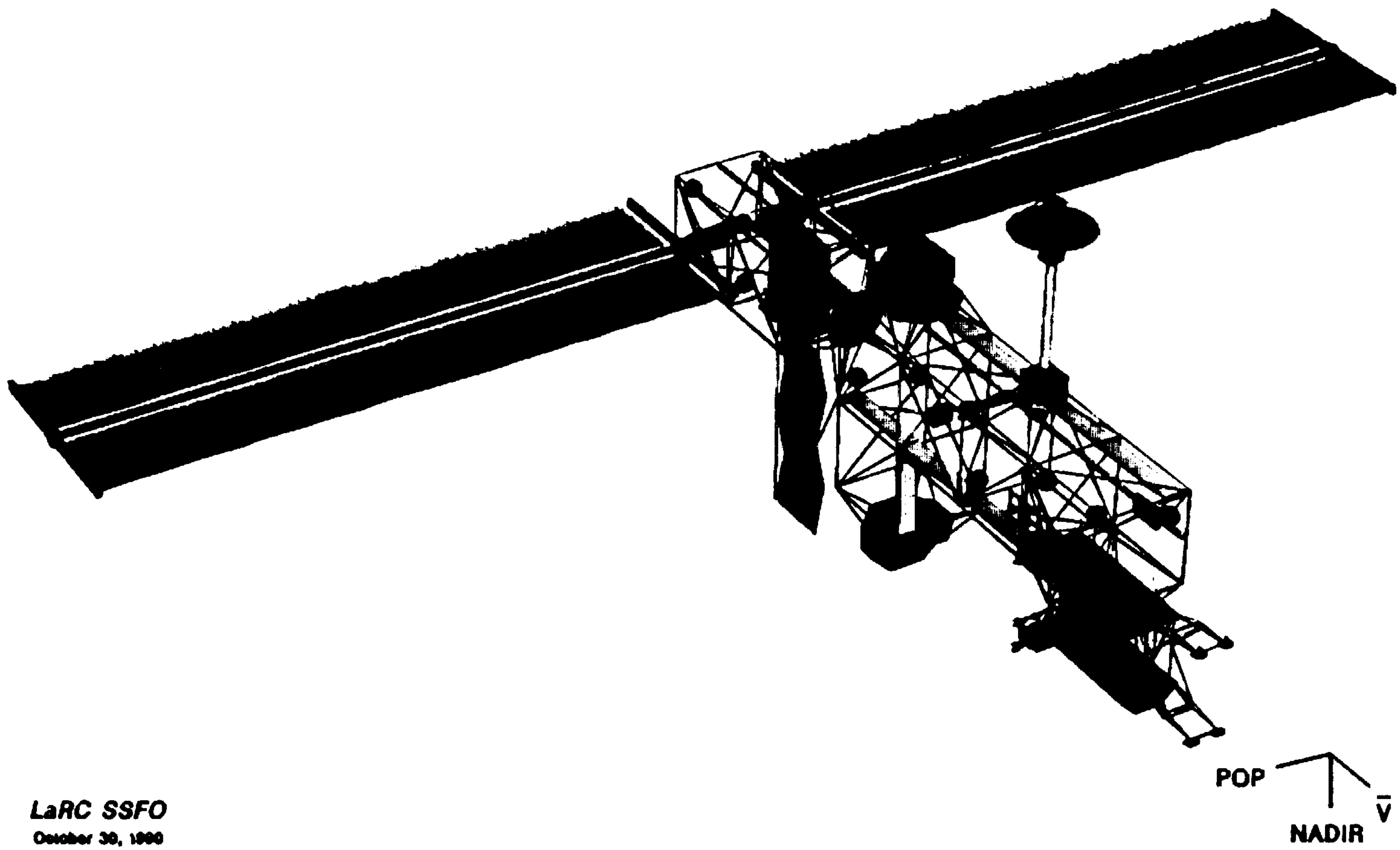
LaRC SSFO

MB2

MB2 – Arrow

The figure opposite depicts the MB2 configuration flown in an *arrow* orientation, with the transverse boom aligned along the velocity vector direction.

MB2 - Arrow



LaRC SSFO
October 30, 1990

MB –2 Arrow Results Summary

This table summarizes the fuel requirements for MB–2 flown in a feathered arrow attitude. With a ballistic coefficient of 79, the lifetime from the rendezvous altitude of 224 Nm is 580 days.

Compared to gravity gradient, the arrow oriented MB–2 requires even less fuel to meet the downtime – reboost interval scenarios studied. However, preliminary RCS attitude control analyses for the unstable arrow configuration indicates excessive fuel requirements which would exceed the available fuel for downtimes in excess of 6 months.

NASA — FREEDOM

Configuration : **MB-2**
(arrow orientation)
Nominal Launch Date : June, 1995
Nominal Rendezvous Altitude : 224 Nm

Lifetime to 150 Nm : 580 days (feathered);

Tank Capacity : 9000 lb
Nominal Fuel available [1] : 8840 lb

Flight mode	Reboost Interval (months)	Fuel Requirements (lb)		
		6 month downtime 6-15-1999	1 year downtime 6-15-1999	2 year downtime 6-15-1999
Arrow	3	500	1200	2900
(BC = 79)	6	400	1000	2400
26 lb fuel/day req'd for atti-tude control	12	1400 *	800	2000
Attitude Control Fuel Req'ts		4800	9500	19,000

1. Level 2 Stage Summary Databook - 1/89

* *de-boost required*

LaRC SSFO

arrow

CONCLUSIONS MB–2

Assuming that the nominal amount of fuel (8840 lb) is available at the time of assembly of flight MB–2, there appears to be no propellant or lifetime problems for the full power mode (sun–tracking), or the reduced power mode (arrays feathered). However, the arrow mode orientation requires excessive propellant to maintain attitude control for more than 6 months, and thus is *not* a recommended profile strategy for consideration for either nominal or contingency operations.

CONCLUSIONS

MB–2

Assuming that the nominal amount of fuel is available (8840 lb) :

Gravity gradient attitude mode : No propellant or lifetime problems for full power mode (sun–tracking), even though mildly unstable due to aerodynamic torques on articulating arrays.

(No propellant or lifetime problems for the reduced power (stable) feathered mode)

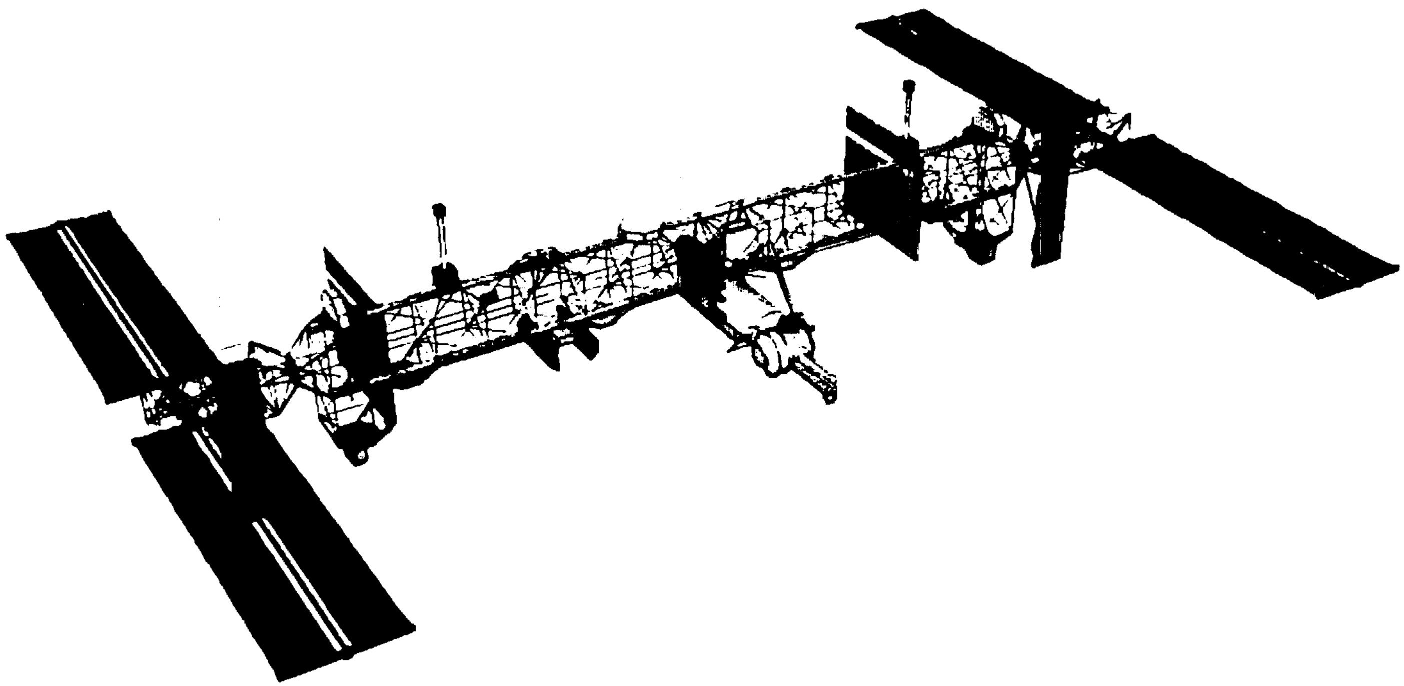
Arrow mode : although yielding longer orbital lifetimes, is an unstable attitude (with non–optimal RCS jet nozzel locations) requiring excessive attitude control propellant, and hence is *not* a recommended attitude profile strategy for either nominal or contingency operations.

Gravity gradient attitude mode recommended for contingency operations .

Man – Tended Capability (MTC)

The figure opposite depicts the 37.5 kW MTC configuration flown in an LVLH attitude. It is assumed that the CMGs are available for attitude control at this time.

Man-Tended Capability (MTC)



LaRC SFFO
October 30, 1989

MTC Results Summary

The table summarizes the fuel requirements for various combinations of rendezvous interrupt downtimes, and reboost interval strategies for the MTC. The nominal assembly date is assumed to be June, 1996. The lifetime from the nominal rendezvous altitude of 228 Nm is 90 days when sun–tracking, 165 days with feathered PV arrays. The tank capacity at the time of PMC completion is 18,000, of which 13,790 lb of hydrazine is expected to be available[1].

The top half of the table lists the results for the full power, or sun–tracking mode, where the ballistic coefficient was determined to be 31.2. The bottom half of the table lists the feathered array results, where the ballistic coefficient was 77.4 Kg/m^2.

All combinations of reboost scenarios and contingency downtimes show fuel requirements of less than the predicting available propellant except for the cases of a 2 year downtime with 3 or 6 month reboost intervals. A 12 month reboost strategy for the 2 year downtime contingency requires less fuel than the available amount; however, the PMC must be reboost to an altitude of 301 Nm to achieve the 1 year lifetime to 150 Nm altitude.

1 Level 2 Stage Summary Databook – 12/89

NASA — FREEDOM

Configuration : **Manned Tended Configuration**
Nominal Launch Date : June, 1996
Nominal Rendezvous Altitude : $\boxed{228\ Nm}$

Lifetime to 150 Nm : 90 days (sun-tracking); 165 days (feathered)
Tank Capacity : 18,000 lb
Nominal Fuel available [1] : 13,790 lb

Flight mode	Reboost Interval (months)	Fuel Requirements (lb)		
		6 month downtime 6-1-00	1 year downtime 6-1-00	2 year downtime 3-1-00
Sun-tracking (BC = 31.2)	3	5100	11,000	21,600
	6	4000	8600	16,900
	12	11,000 *	6300	12,400 301 Nm
Feathered (BC = 77.4)	3	2500	5400	10,600
	6	2150	4650	9200
	12	6200 *	3750	7400

1. Level 2 Stage Summary Databook - 12/89

* *de-boost required*

LaRC SSFO

MTC_228

CONCLUSIONS MTC

Assuming that the nominal amount of advertised fuel is available at the time of MTC assembly (i.e., 13,790 lb), there are no propellant or lifetime problems for downtimes of 1 year or less, even assuming full power sun–tracking mode. Two year downtimes while sun–tracking the PV arrays can be accommodated utilizing a 12 month reboost strategy up to an altitude of 301 Nm. Transition to a reduced power mode in the event of a contingency rendezvous interruption by feathering the PV arrays approximately doubles the propellant and lifetime margins, and allows reboost intervals of less than 12 months, even in the event of a 2 year downtime. This would be the recommended strategy if it became obvious that the schedule interruption may be of substantial duration.

CONCLUSIONS
MTC

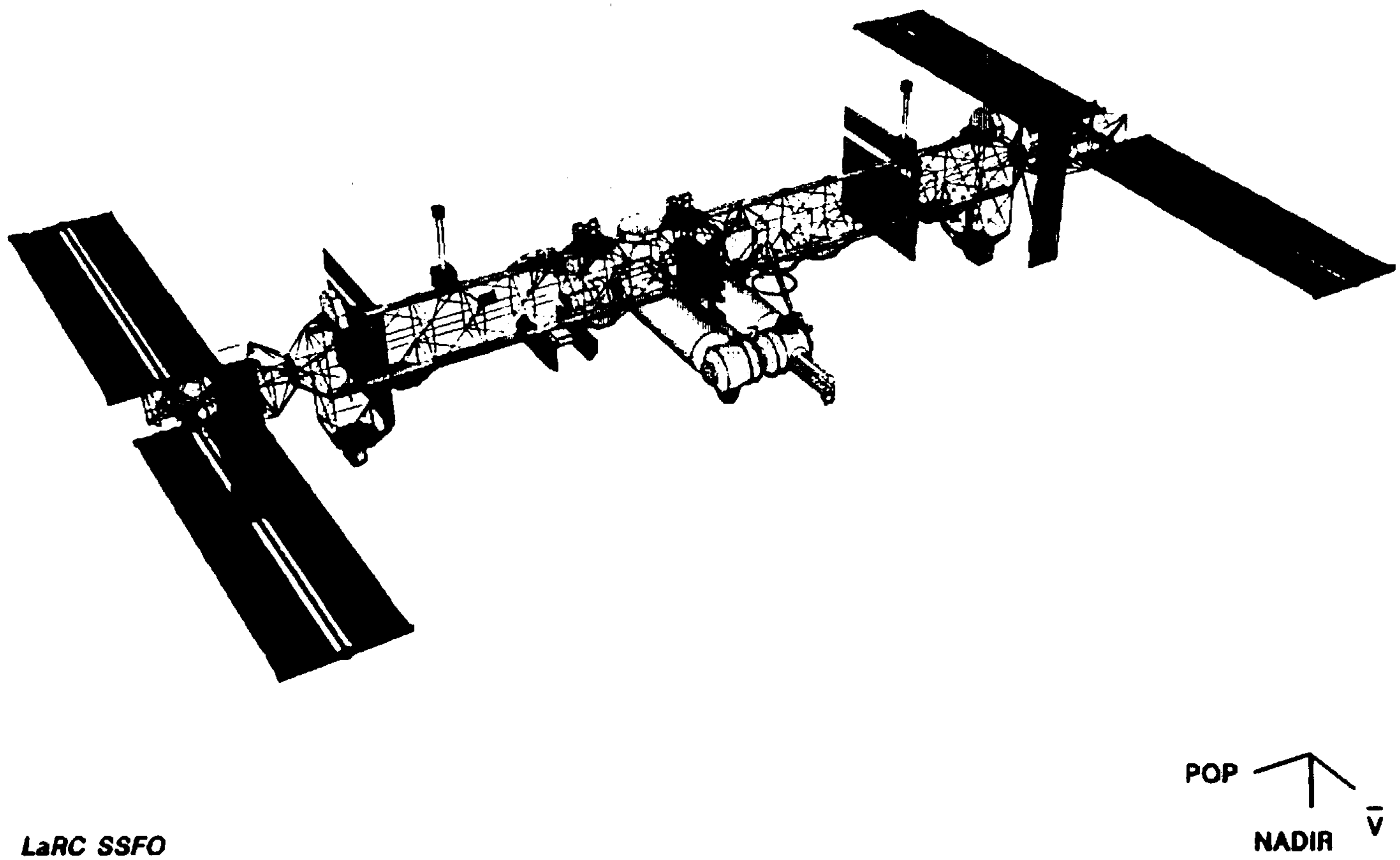
Assuming that the nominal amount of fuel is available (13,790 lb) :

- No propellant or lifetime problems for downtimes $\leq$ 1 year, even assuming full power mode (sun-tracking).
- 2 year downtime can be accommodated with full power (sun-tracking) utilizing 12 month reboost strategy.
- Transition to reduced power mode (feathered arrays) approximately doubles propellant and lifetime margins, and allows reboost intervals of less than 12 months in the event of a 2 year downtime.

Permanently Manned Capability (PMC)

The figure opposite depicts the PMC configuration flown at the nominal LVLH attitude orientation.

Permanently Manned Capability (PMC)



LaRC SSFO
October 30, 1990

OPTIMIZED POWER AVAILABILITY DURING FEATHERING OPERATIONS
(Solstice)

Feathering the photovoltaic arrays decreases drag, increases orbit lifetime and reduces atomic oxygen degradation effects on the PV array surfaces. The trade–off is a reduction in power generation capability. For an LVLH attitude, the outboard truss can be oriented so that the arrays are always edge–on to the velocity direction. The beta gimbal degree of freedom can then be used to maximize the available power.

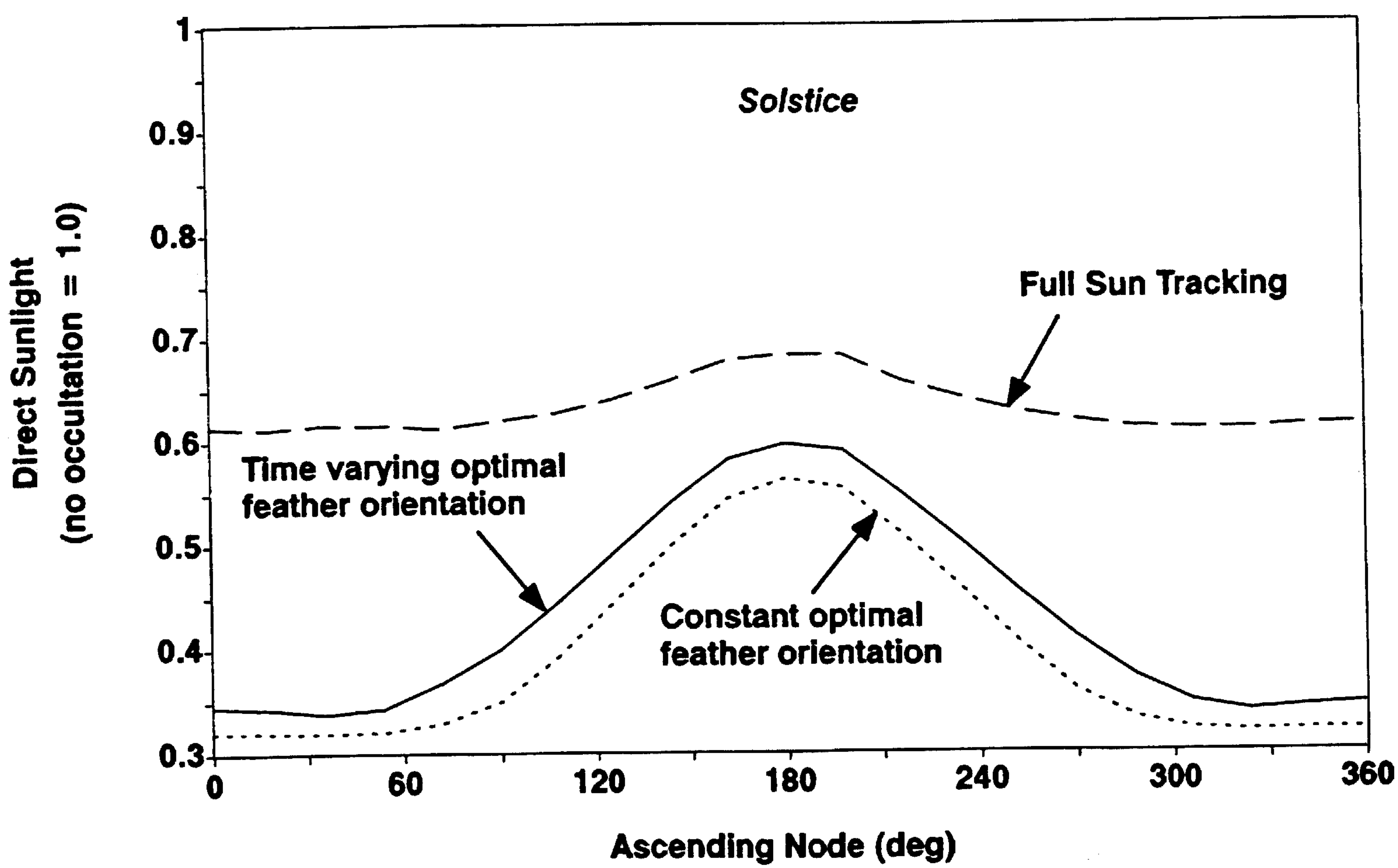
Both optimal *constant* (over an orbit) beta gimbal strategy and optimal *time varying* beta gimbal strategies can be used to maximize power. The graph illustrates the power availability along the vertical axis (normalized to the power obtained without Earth occultation) for full sun–tracking (with occultation effects) and optimal beta gimbal strategies (with occultation effects) for various ascending nodes on winter or summer solstice.

The power availability using optimal beta gimbal strategies peaks at an ascending node of 180 degrees. The feathering power availability (ratio of normalized power with optimal constant beta tracking to normalized power with full sun tracking) using optimal constant beta gimbal varies from 83% to 51%. Thus the feathering power loss varies from 17% to 49% during solstice geometry conditions.

Optimal time varying beta gimbal strategies provide about 2–5% more power than constant beta gimbal strategies, but may require large angular rates. This may not be feasible from an operational, attitude control, or structural dynamics point of view.

NASA FREEDOM

OPTIMIZED POWER AVAILABILITY DURING FEATHERING OPERATIONS



The feathering power loss varies from 17% to 49%

LaRC SSFO

OPTIMIZED POWER AVAILABILITY DURING FEATHERING OPERATIONS (Equinox)

The power availability using optimal beta gimbal strategies peaks at 90 and 270 degree ascending nodes for spring or autumnal equinox days. The feathering power availability using optimal constant beta gimbal varies from 63% to 51%. Thus the feathering power loss varies from 37% to 49%, somewhat more (on average) then for the solstice conditions. For comparison purposes, a beta gimbal angle locked at 0 degrees results in a 53.6% average power reduction over a year compared to full sun-tracking.

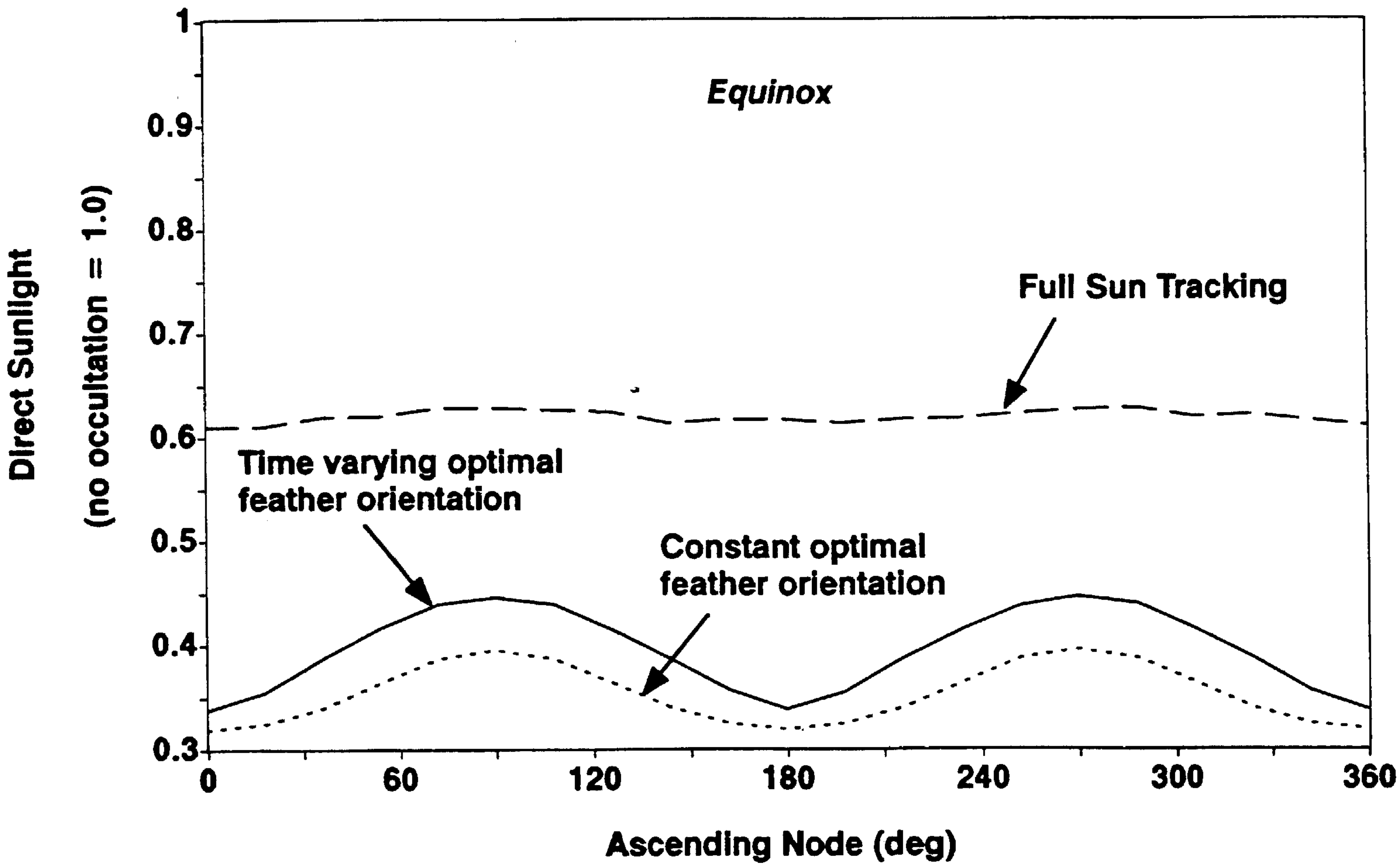
Optimal time varying beta gimbal strategies provide about 2-5% more power than constant beta gimbal strategies, but may require large angular rates as discussed previously.

In summary, feathered array operations can be utilized to increase orbit lifetime in the event of a contingency rendezvous interruption, in conjunction with optimal PV array beta gimbal angle strategies to maximize the amount of power generated during feathered operations.

NASA

FREEDOM

OPTIMIZED POWER AVAILABILITY DURING FEATHERING OPERATIONS



The feathering power loss varies from 37% to 49%

LaRC SSFO

PMC Results Summary

The nominal PMC launch date is July, 1997. The nominal rendezvous altitude is 223 Nm, which yields a 90 day lifetime to 150 Nm when sun–tracking, and a 247 day lifetime if feathered. The tank capacity remains at 18,000 lb, but only 7215 lb of hydrazine remains prior to the next resupply flight.

With these assumptions, and the relatively massive PMC configuration, practically all of the reboost fuel requirements for the downtime scenarios studied for the full sun–tracking flight modes (ballistic coefficient = 57.3) exceed the amount of propellant available. Several of the feathered flight modes (BC = 136.5) scenarios analyzed also have fuel requirements which exceed available propellant.

NASA — FREEDOM

Configuration : **Permanently Manned Configuration**

Nominal Launch Date : July, 1997

Nominal Rendezvous Altitude : 223 Nm

Lifetime to 150 Nm : 90 days (sun–tracking); 247 days (feathered)

Tank Capacity : 18,000 lb

Nominal Fuel available [1] : 7215 lb

Flight mode	Reboost Interval (months)	Fuel Requirements (lb) 6 month downtime 12-1-00	1 year downtime 9-1-00	2 year downtime 3-1-00
Sun–tracking (BC = 57.3)	3	7900	15,100	28,800
	6	6300	12,500	23,900
	12	16,200 *	9700	18,300 280 Nm
Feathered (BC = 136.5)	3	3800	7300	13,800
	6	3400	6600	12,600
	12	8900 *	5600	10,600

1. Level 2 Stage Summary Databook - 12/89

* de–boost required

LaRC SSFO

PMC_223

CONCLUSIONS PMC

Maintaining full power mode (sun–tracking) requires at least 1 ELV fuel resupply for most of the downtime scenarios analyzed, and hence, is *not* a recommended strategy for contingency PMC operations.

At the time of a downtime annunciation, immediately going to a feathered attitude assures an adequate lifetime for downtimes of 1 year or less, assuming at least a 6 month reboost. However, 1 ELV fuel resupply is still required, even for feathered arrays, in the event of a 2 year downtime and atmospheric conditions as described in the ground rules.

As an aside, the most stringent phase of assembly from an orbit lifetime / reboost fuel propellant point of view appears to occur 2 flights after PMC, i.e., flight 15 (logistics flight 2), where the available remaining fuel is even less.

From an ECLSS point of view, the tightest crew related consumables constraints appears to be the food supply. Following PMC assembly departure, there is a nominal food supply to last 164 days (crew of 4). Hence, for all delayed rendezvous scenarios studied, additional ELV resupply flights would be required to maintain a crew presence. Otherwise, the crew would have to depart via ACRV within 6 months. Two flights subsequent to PMC, the nominal food supply is down to 73 days, just prior to the next regularly scheduled food resupply.

It is worthwhile to note that at the time of a contingency downtime annunciation, although the *duration* of the downtime is not known a priori, the exact date and a reasonable knowledge of the atmosphere (nominal, 2 sigma, etc) will be known. Hence, the conclusions based on the propellant reboost/orbit lifetime results presented should be interpreted as to what would be required in a conservative atmospheric environment consistent with the assumptions discussed previously. If, in actuality, the assembly date was *not* slipped, or the solar cycle *not* shifted, the reboost propellant requirements would be smaller, and the corresponding orbital lifetimes longer.

CONCLUSIONS
PMC

Maintaining full power mode (sun–tracking) *requires* at least 1 ELV fuel resupply for most of the downtime scenarios studied, and hence, is *not* a recommended strategy for PMC.

At the time of downtime annunciation, immediately going to a feather attitude assures an adequate lifetime for downtimes of $\leq$ 1 year, assuming at least a 6 month reboost. However, 1 ELV fuel resupply is required to maintain a viable lifetime in the event of a 2 year downtime.

The *tightest* pinch point from an orbit lifetime/ reboost fuel propellant point of view appears to occur 2 flights after PMC, i.e., flight number 15 (logistics flight 2).

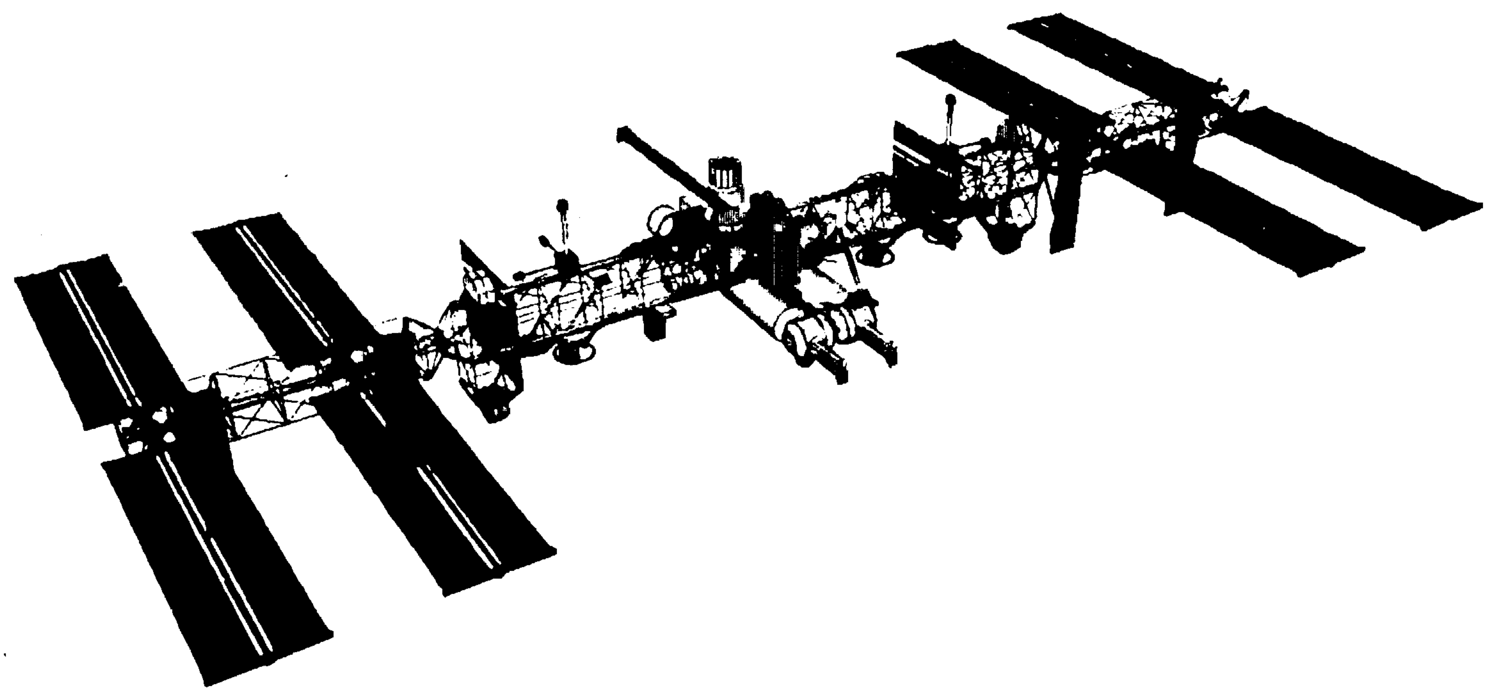
From an ECLSS point of view, the tightest crew related constraint is food supply. There is a nominal supply of 164 days following PMC departure, which can be extended about 2 weeks with crew rationing. Hence, for *all* delayed rendezvous scenarios studied (6, 12, and 24 months), additional ELV resupply flights would be required to maintain a crew presence, else, the crew would have to depart via ACRV within 6 months. The *tightest* pinch point occurs 2 flights later, just prior to the next regularly scheduled logistics flight, when the food supply is down to only 73 days.

Note : At the time of a contingency downtime annunciation, although the *duration* of the downtime is not known a priori, the exact date and a reasonable knowledge of the atmosphere (nominal, 2 sigma, etc.) will be known. Hence, the conclusions based on the propellant reboost/orbit lifetime results presented should be interpreted as to what would be necessary in a conservative situation consistent with the assumptions discussed previously. If, in actuality, the assembly date was *not* slipped, or the solar cycle *not* shifted, the reboost propellant requirements would be smaller, and the corresponding orbital lifetimes longer.

Assembly Complete (AC)

The figure opposite illustrates the Assembly Complete Configuration, shown with 75 kW power generation capability and both international partners present.

Assembly Complete (AC)



LaRC SSFO
October 30, [illegible]

Assembly Complete Results Summary

The table summarizes the Assembly Complete reboost fuel requirement results obtained during the analysis. The nominal assembly date is June, 1999. The nominal assembly altitude is 227.5 Nm., which yields a 90 day lifetime to 150 Nm when sun–tracking, and a 287 day lifetime with PV arrays feathered. The average ballistic coefficient is 49.9 sun–tracking; 137.7 feathered. The total propellant tank capacity at this point in the assembly process is planned to be 26,880 lb. The expected fuel availability at this point in the assembly process is expected to be about 23,155 lb.

Looking at the bottom half of the table, all fuel requirements for all reboost strategies studied, up to a 2 year downtime, are less than the fuel availability. In other words, in the event of a contingency missed rendezvous, feathering the arrays assures at least a 2 year lifetime if the advertised fuel availability is present.

The top half of the table indicates that for sun–tracking modes, 1 year downtimes can be accommodated with 6 or 12 month reboost strategies (but not 3 months). However, 2 year downtimes cannot be accommodated with the advertised fuel availability, and would require additional fuel logistics flights to sustain a 2 year lifetime.

NASA FREEDOM

Configuration : **Assembly Complete**

Nominal Launch Date : June, 1999

Nominal Rendezvous Altitude : 227.5 Nm

Lifetime to 150 Nm : 90 days (sun–tracking);
287 days (feathered)

Tank Capacity : 26,880 lb

Nominal Fuel available [1] : 23,155 lb

Flight mode	Reboost Interval (months)	Fuel Requirements (lb)		
		6 month downtime 12-1-00	1 year downtime 9-1-00	2 year downtime 3-1-00
Sun–tracking (BC = 49.9)	3	12,800	24,600	46,300
	6	10,400	20,400	38,700
	12	25,900 *	15,600	29,700 285 Nm
Feathered (BC = 137.7)	3	5500	10,500	19,700
	6	4900	9500	18,000
	12	12,900 *	8100	15,300

1. Level 2 Stage Summary Databook *plus* Turbo   * *de–boost required*

LaRC SSFO

AC_227

CONCLUSIONS
Assembly Complete

Assuming that the advertised amount of propellant (23,155 lb) is available at the time of the annunciation of the delayed assembly flight, full power mode (sun–tracking) requires an ELV fuel resupply to achieve a 2 year lifetime. One year lifetimes can be achieved with 6 or 12 month reboost intervals.

In the event of such a contingency downtime scenario, it is likely that the station will power down, and assume a feathered PV array orientation. Feathering more than doubles propellant and lifetime margins, and accommodates all downtime scenarios studied utilizing any reboost interval strategy analyzed.

From an ECLSS point of view, a 160 day supply of food exists to support a nominal crew of 8 following assembly complete. This interval can be extended to up to 172 days if the food is rationed. Air and water supplies will be in excess of 160 days. Thus, the crew cannot remain on station for the entire duration in the event of a 2 year downtime without a food logistic resupply.

It is again worthwhile to note that at the time of a contingency downtime annunciation, although the *duration* of the downtime is not known a priori, the exact date and a reasonable knowledge of the atmosphere (nominal 2 sigma, etc) will be known. Hence, the conclusions based on the propellant reboost/orbit lifetime results presented should be interpreted as to what would be required in a conservative atmospheric environment consistent with the assumptions discussed previously. If, in actuality, the assembly date was *not* slipped, or the solar cycle *not* shifted, the reboost propellant requirements would be smaller, and the corresponding orbital lifetimes longer.

CONCLUSIONS

Assembly Complete

Assuming that the nominal amount of fuel is available (23,155 lb) :

- Full power mode (sun-tracking) requires ELV fuel resupply to achieve a 2 year lifetime. A one year lifetime requires > 3 month reboosts to avoid ELV fuel resupply.
- Transition to reduced power mode (feathered arrays) more than doubles propellant and lifetime margins, and can accommodate all downtime scenarios studied utilizing any reboost interval strategy studied.

From an ECLSS point of view, a 160 day supply of food exists (>160 days for oxygen and water) to support a nominal crew of 4 (172 days if rationing) following assembly completion. Thus, the crew cannot remain for an entire 2 year downtime without a food resupply.

Note : At the time of a contingency downtime annunciation, although the *duration* of the downtime is not known a priori, the exact date and a reasonable knowledge of the atmosphere (nominal, 2 sigma, etc.) will be known. Hence, the conclusions based on the propellant reboost/orbit lifetime results presented should be interpreted as to what would be necessary in a conservative situation consistent with the assumptions discussed previously. If, in actuality, the assembly date was *not* slipped, or the solar cycle *not* shifted, the reboost propellant requirements would be smaller, and the corresponding orbital lifetimes longer.

Summary and Recommendations

During the course of this analysis, it was determined that all of the *Freedom* assembly phases studied beyond flight MB–1 must be assembled at an altitude *above* those values carried in the Level 2 stage Summary Databook (220 Nm flights 1 to 5; 190 Nm flights 6 and beyond) in order to comply with the altitude strategy defined in CR BJ020361A. Assembly at the databook altitudes would drastically *degrade* the contingency scenario results obtained in this study. The implication of raising the assembly altitudes is to reduce 100 lb of payload capability for every 1 Nm increase in assembly altitude.

Prior to MTC, the main viability issue identified was the passive flight MB–1, which would need to be assembled at an altitude above 220 Nm in order to assure a 2 year lifetime if either a significant launch slip, or a significant shift in solar cycle peak flux were to occur. In the event of no active CMG control for assembly flight 2, it is recommended to orient the spacecraft in a gravity gradient orientation rather than an arrow configuration because of the attitude controllability issues identified.

Summary and Recommendations

All assembly flights studied must be assembled at an altitude *higher* than those carried in the Level 2 Stage Summary Databook in order to comply with the altitude strategy defined in CR BJ020361A (assumes 2σ atms). Assembly at Level 2 Stage Summary Databook values (220 Nm flights 1 to 5 ; 190 Nm flight 6 and beyond) would drastically *degrade* the contingency scenarios results obtained. Note that there is an approximate 100 lb reduction in payload to orbit for every 1 Nm increase in assembly altitude.

Prior to MTC, the main viability issue identified was the passive flight MB–1, which will need to be assembled at an altitude higher than 220 Nm in order to assure a 2 year lifetime if there is *either* a significant launch date slip, or a significant shift in solar cycle peak flux occurrence. It is recommended to operate flight MB–2 in a gravity gradient attitude, as opposed to an arrow attitude because of the attitude control issues identified.

It is recommended that a resupply strategy be programmatically implemented to accommodate 2 year contingency scenarios.

Summary and Recommendations (concluded)

Subsequent to the assembly of MTC, *Freedom* should be configured to fly in a feathered array mode in the event of a contingency downtime. In addition, not all combinations of reboost strategy and downtime duration could accommodate reboost fuel requirements without requiring extra fuel logistic flights to be inserted into the assembly sequence. Crew stay times in the event of contingency missed rendezvous are on the order of a half year.

Utilization of a higher specific thrust propellant (for example, H_2O_2) may be sufficient to maintain positive fuel margins. However, the type of propellant utilized does not address the assembly altitude issue raised with respect to the Stage Assembly Databook lifetime to 150 Nm altitude requirement.

The LaRC SSFO agrees with the assembly altitude (lifetime to 150 Nm) strategy and atmospheric assumptions endorsed by the program, and concurs with the use of these values for the purpose of contingency planning. This approach guarantees a built–in conservatism which may allow the operations team to adopt a different strategy real–time in the event of a contingency downtime on the order of those studied in this analysis when the actual date and atmosphere would be known quantities. However, either food resupply ELV logistic flights, or crew departure via ACRV would be required to accommodate downtimes in excess of 6 months.

As a result of this analysis, it is recommended that a resupply strategy be programmatically implemented to accommodate 2 year downtime contingency scenarios.

Summary and Recommendations (concluded)

Subsequent to the assembly of MTC, *Freedom* should be configured to fly in a feathered array mode in the event of a contingency downtime. In addition, many of the downtime/reboost scenarios analyzed required either :

- a) ELV provided propellant to remain *viable*, or
- b) an extra fuel logistics flight to be inserted into the assembly sequence prior to A/C

Again, it is worthwhile to note that should the actual launch date and atmosphere be close to nominal, no additional measures are required to maintain a viable *station* lifetime through Assembly Complete. However, for contingency planning purposes, the above recommendations must be considered. Furthermore, either ELV *food* resupply flights, or crew departure via ACRV is required in order to accommodate the longer downtime scenarios studied.

Utilization of a higher specific thrust propellant (e.g., H_2O_2) may be sufficient to maintain positive fuel margins and should be studied. However, this still would not address the lifetime to 150 Nm issues identified.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1991

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Space Station Freedom Contingency Reboost and Resupply Strategies

5. FUNDING NUMBERS
476-14-15-01

6. AUTHOR(S)
Patrick A. Troutman, Jonathan N. Cruz, Michael L. Heck, Daniel D. Mazanek, Renjith R. Kumar

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, Virginia 23665-5225

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-104169

11. SUPPLEMENTARY NOTES
Troutman, Cruz: Langley Research Center, Hampton, VA; Heck, Kumar, Mazanek: Analytical Mechanics Associates, Inc., Hampton, VA

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited

Subject Category 18

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The objective of this study was to determine the requirements necessary to ensure a viable space station in the event of a delay in the date of the first element launch, and/or in the event that the nominal assembly sequence is interrupted, perhaps due to a delay in the space shuttle launch schedule. Orbit lifetimes, reboost fuel requirements, and controllability requirements were calculated for each stage of the space station assuming anywhere from a 6 to 24 month delay/interruption in the baseline space station assembly sequence. These results were assessed in order to formulate strategies to assure station viability in the presence of assembly sequence delays and interruptions.

14. SUBJECT TERMS
Space Station Freedom
Reboost
Orbit lifetime

15. NUMBER OF PAGES
78

16. PRICE CODE
A05

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT
UL